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ASSESSMENT OF WATER BALANCE OF A WATERSHED USING SWAT MODEL FOR WATER RESOURCES MANAGEMENT

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ABSTRACT

An attempt has been made in this study to assess the hydrological behavior of the Kurumali sub basin of Karuvannur river basin using SWAT model and other geospatial technologies. All the thematic maps and attribute information of the watershed have been collected from various Government agencies. SWAT model has been set up for the Kurumali sub basin by inputting the digital thematic maps, physical properties of soil and climatic parameters. Total area of the watershed corresponding to the outlet chosen at Kurumali is 423 km^2 and its elevation varies from 10 to 650 m. Six different land use and eight soil types were present in the catchment. Calibration and validation of the model have been done by comparing the river flow prediction with the observed values. Nash Sutcliff Efficiency (NSE) and coefficient of determination (R^2) has given very high values for the calibration (0.88 and 0.96) and validation (0.90 and 0.99) periods respectively. The calibrated model has been used to predict the important hydrologic processes viz. surface runoff, lateral flow, base flow and ET and it was found that base flow amounts to 64 %, lateral flow 12 % and surface runoff 9 % of the annual rainfall. The study has revealed that SWAT model can effectively be used in the simulation of river flow and for predicting the water balance of a river basin in the humid tropic. Water balance information of the basin is of great use in planning water conservation, drainage and flood control.

KEYWORDS: Water balance, Arc GIS, SWAT model, NSE and R^2

INTRODUCTION

The components of water balance of a basin are influenced by climate, the physical characteristics of the watershed such as morphology, landuse and soil. Understanding the relationship between these physical parameters and hydrological components are very essential for any water resources development related work. Since the hydrologic processes are very complex, their proper comprehension is essential and for this watershed models are widely used. This study utilises the capability of SWAT model in analysing the water balance components of ahumid tropic watershed in the Indian peninsular region. The most important hydrologic elements from the water management point of view are surface runoff, lateral flow, baseflow and evapotranspiration. There are a number of integrated physically based distributed models. Amoung them, researchers have identified SWAT as the most promising and computationally efficient (Neitsch *et al.*, 2005). Hence, in this study, an attempt has been made to study calibration, validation of the SWAT model and to determine the important hydrologic components of a river basin with focus on water conservation and management. The specific objective of the study lies in assessing the water balance component of a humid tropic river basin to make water resources planning and management more objectively.

MATERIALS AND METHODS

Study area

Kurumali sub basin of Karuvannur river in Thrissur district, Kerala was selected as the study area as shown in Fig. 1. The Kurumali river, locally known as Kurumali Puzha is one of the two important tributaries of Karuvannur river. The Karuvannur river lies in the latitude longitude range of 10°15' N to 10° 40'N and 76°00' E to 76° 35' E. Total catchment area of the river is 1054 km^2. Physiographically, the river basin can be divided into 3 divisions viz. low land (0 to 7.5 m), mid land (7.5 to 75 m) and high land (>75 m). The annual average rainfall in the low land, mid land and high land of the basin has been estimated as 2858 mm, 3011 mm and 2851 mm respectively. About 60 per cent of the annual precipitation is received during South West monsoon period, 30 per cent from North East monsoon and 10 per cent through the summer and pre monsoon period. The outlet of the watershed has been selected at Kurumali in Muriyad Grama panchayath with a latitude and longitude of 10°24'4" North and 76°16'56" East respectively, as river flow data is available for this section.

Tools and techniques used

Digital maps required for the watershed viz. digital elevation model, drainage map and soil map have been prepared using Arc GIS 10.3. Land use map required for the study area has been prepared using ERDAS Imagine 2015. Watershed model used is SWAT developed by USDA ARS. SWAT is a complex integrated river basin scale model which operate either on daily or hourly time step (Arnold et al., 1998, Jayakrishnan et al., 2005 and Bouraoui et al., 2005).

Equations of watershed hydrology

SWAT uses water balance equation for the watershed to simulate the hydrologic processes. the basic water balance equation is given as:

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \quad (3.1)$$

Where, SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day i (mm H_2O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm H_2O), E_a is the amount of evapotranspiration on day i (mm H_2O), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H_2O), and Q_{gw} is the amount of return flow on day i (mm H_2O).

The daily surface runoff is given by

$$Q_t = \frac{(R_t - 0.2S)^2}{(R_t + 0.8S)} \quad (3.2)$$

Where, Q_t is the accumulated runoff or rainfall excess, R_t is the rainfall depth for the day and S is the retention parameter and calculated as

$$S = 25.4\frac{1000}{CN} - 1 \quad (3.3)$$

Where, CN is the curve number for the day. 0.2S is taken as Initial abstraction I_a. Runoff will occur only when $R_t > 0.2S$.

Climate, hydrologic and physiographic data

The daily rainfall for a period of 20 years (1993 to 2012) has been collected from Echipara and Muply raingauge station situated within the watershed. The daily river flow of Kurumali basin at Kurumali outlet has been collected for the same period from Data Dissemination Centre, Jalavijnana Bhavan Ambalamukku, Trivandrum. The rest of the weather data other than rainfall viz., temperature, wind speed, relative humidity, sunshine hours and evaporation were collected from Meteorological Observatory, Kerala Agricultural University (KAU), Vellanikkara for the above mentioned same time period. The Digital Elevation Model (DEM) in ESRI grid format with 30 m resolution of Shuttle Radar Topography Mission (SRTM) was collected from the Earthexplorer.usgs.gov. Soil data of Kurumali sub basin comprising of soil texture and organic carbon has been collected from Department of Soil Survey and Soil Conservation, Kerala and Kerala Forest Research Institue (KFRI), Peechi. Soil hydraulic conductivity, electrical conductivity and bulk density were obtained by Soil Plant Atmosphere Water (SPAW) hydrologic budget model developed by Keith Saxton, United States Department of Agriculture (USDA) Agricultural Research Service (ARS). Landuse map has been prepared by the supervised classification of the multispectral LISS III imagery of IRS P6 procured from National Remote Sensing Agency (NRSA), Hyderabad. Topographic map prepared in 1:50,000 scale was collected from Survey of India (SOI) bearing numbers 58B03, 58B06, 58B07 and 58B11 for the study area.

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SWAT Model setup

The entire map based and tabular data base for the SWAT model has been generated for the study area. SWAT model has been input with the error corrected SRTM DEM, land use map prepared through the supervised classification, soil map. The process involved in SWAT model set up SWAT project creation, Watershed delineation, HRU Analysis, writing input table, editing the input and SWAT Simulation. SWAT delineates the main watershed boundary and the main watershed into sub watersheds based on the slope direction of the DEM supplied (SRTM DEM of 30 m resolution). The projection assigned for the DEM was WGS_1984_UTM_Zone 43 N. The outlet is defined at the location of river flow monitoring station. All the main watershed topographic parameters and those of the sub watersheds were calculated. Total area of the watershed is 422.57 km^2 with a maximum length is 32.35 km and maximum width 20.37 km with a length width ratio of 32: 20. Twenty five sub watersheds have been delineated in the main watershed by assigning a threshold area for the generation of stream lines as 1000 ha.

After the land use and soil maps are input, a total of 816 Hydrologic Response Unit (HRU) are generated. Land use category look up table and soil type look up tables are used to reclassify the land use and soil to make it SWAT model compatible. The model requires daily data for precipitation and temperature that is provided by the user in the text format and is stored in the project database. Remaining climatic data viz. humidity, solar radiation and wind velocity can either be supplied or generated by the model as the user specified weather generation file. Next, the model prepares all the data set such as topographic, land use, soil, and climatic required for the model simulation runs. Then the SWAT model is ready to run and calculate the hydrologic processes viz. surface runoff, lateral flow, base flow and evapotranspiration.

Model calibration and validation

Physically based distributed watershed models should be calibrated before they are put in use in the simulation of hydrologic processes. This is to reduce the uncertainty associated with the model prediction. Observed river flow at Kurumali river gauging station managed by the Department of Water Resources is used for comparison of the simulated data. The model has been calibrated with 4 years of observed river flow from 1996 to 1999 and is validated using 2 years data from 2000 to 2001. The mean monthly river flow shows that the river is live only during the period from June to December. From January to May, the stream is completely dry. This reveals that the lag time of base flow is very less and all stored groundwater get depleted very quickly.

Figure:

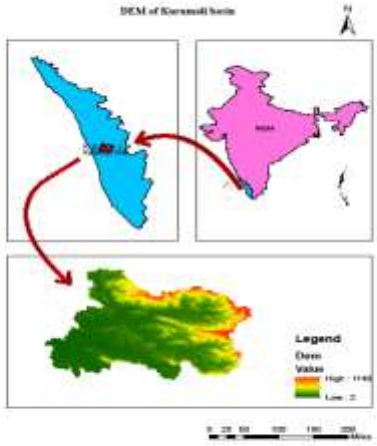

Fig. 1. Delineation of Kurumali Sub basin

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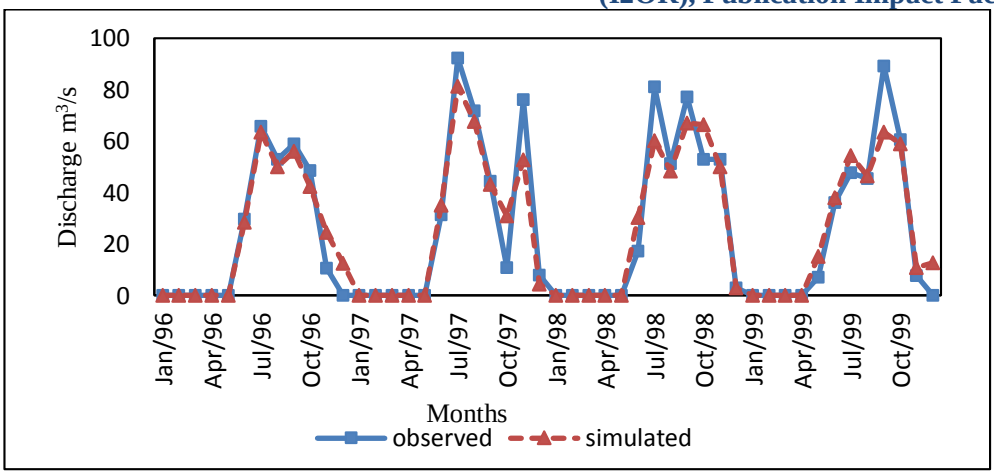

Fig.2. Monthly average river flow (Calibration period)

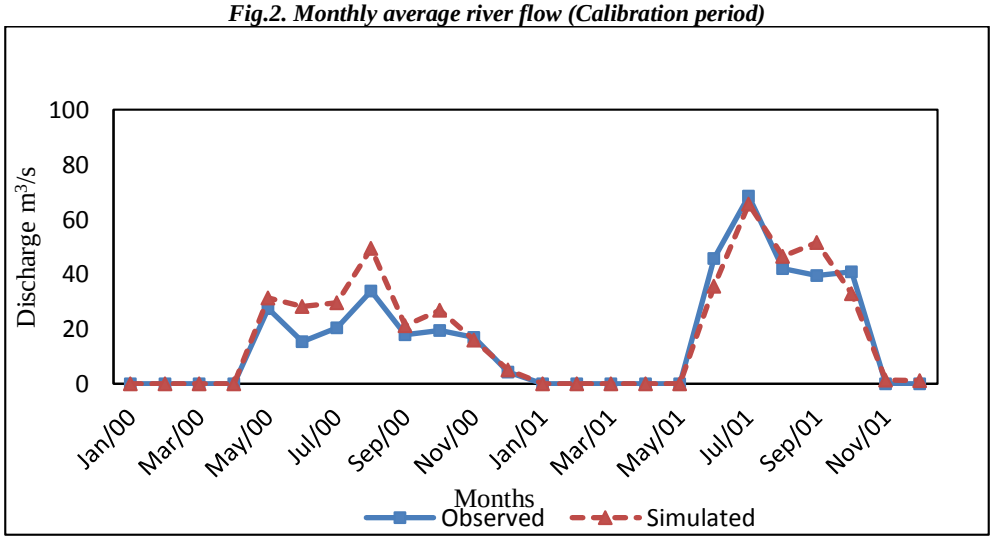

Fig. 3 Monthly average river flow (Validation period)

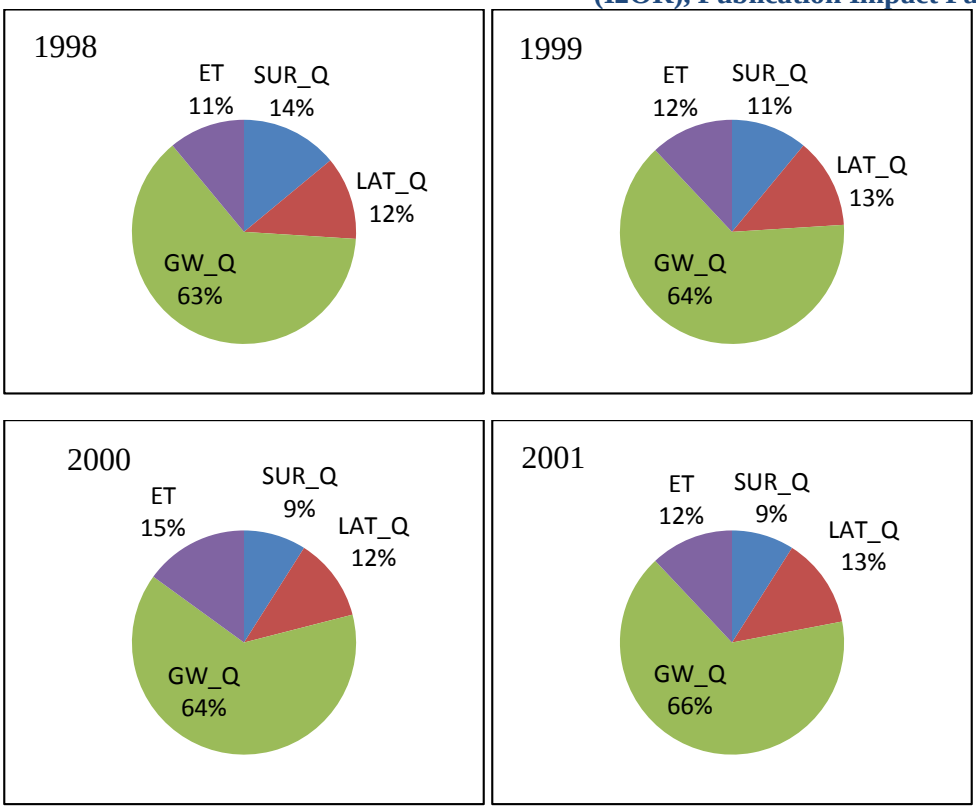

Fig. 4. Water balance of Kurumali basin for different years expressed as a percentage of annual rainfall

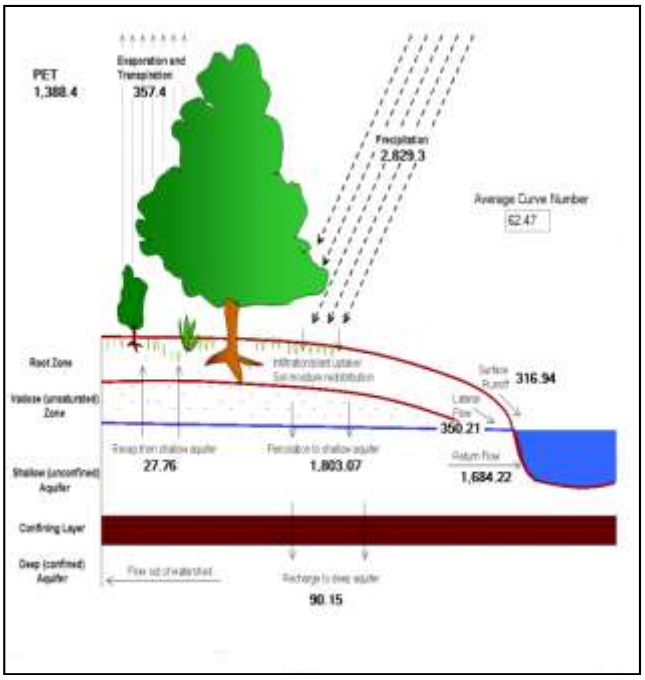

Fig. 5 Schematic representation of hydrologic cycle.

RESULTS AND DISCUSSION

Soil map, slope map and landuse map have been generated. Similarly the area description of each maps were also generated using SWAT model.

Sensitivity Analysis

The sensitivity analysis for the flow parameters of the model for Kurumlai watershed shows that alpha base flow factor (Alpha_Bf) is the most sensitive parameter among all other factors. Curve Number (Cn2) ranks second in parameter sensitivity followed by threshold water depth for base flow (Gwqmn) (Table 1). The results of sensitivity analysis matches with other studies made for the neighbouring river basins (Sathian, 2009). Sensitivity analysis makes the task of calibration of the model easier.

Calibration and validation of swat model

Calibration and validation of the model assumes great significance in order to get reliable results. The model has been calibrated with 4 years of observed river flow from 1996 to 1999 and is validated using 2 years data from 2000 to 2001.The annual model output of the river flow for the calibrated one shows close matching with the observed one. The estimated and observed river flow for the calibration and validation period are shown in fig 2 and 3. Close matching between the observed and estimated flow for the calibration period could be obtained. The statistical analysis have shown very high NSE of 0.88 and COD of 0.96 for the river flow for the calibration period (Table 2). Corresponding NSE and COD of the model simulation for the validation period were 0.90 and 0.99. The very high NSE and COD are the clear indication of the good model prediction of the river flow. The graphical comparison and the values of R^2 and COD for both the calibration and validation clearly indicate the good predictive capability of the model and the reliability of the model output.

Water balance of the basin

Different components of the water balance of the Kurumali sub basin has been determined using the calibrated and validated SWAT model and the results are presented in fig.4. The most important water balance components considered are surface runoff (SUR_Q), lateral flow (LAT_Q), ground water flow (GW_Q) and evapotranspiration (ET). The study revealed that a properly calibrated watershed model could be of great help in the basin level water balance anlysis. A similar study conducted by Sathian and Syamala (2009), also supporting to this result obtained from the present study. The water balance components are showing variations between years. All the components are shown as percentage of annual rainfall of the respective years. Analysis of the results shows that ground water flow (GW_Q) has the highest share of the water balance with values ranging from 63 per cent (1998) to 66 per cent (2001) of the annual rainfall. It can be seen that surface runoff varies between 9 per cent to 14 per cent of the respective annual rainfalls of the years considered. Lateral flow lies within the range of 12 per cent to 13 per cent of the annual rainfall, and 14 per cent to 15 per cent of the annual river flow. ET as a percentage of annual total rainfall is within the range of 11 per cent to 15 per cent. The average values for Surface runoff, lateral flow, base flow and evapotranspiration of the basin were 306.6 mm, 339.2 mm, 1649.7 mm and 337.5 mm respectively. The table 3 shows the percentage rainfall contributions with respect to all water balance components.

Fig 5 shows the quantified schematic representation of Hydrologic cycle. It is the hydrologic component output obtained from the SWAT model. The hydrologic cycle taking place in the land phase is explained by the figure. Water present in each cycle component of the basin is expressed in mm. The annual average precipitation of Kurumali sub basin obtained for the period starting from 1993 to 2012 was 2829 mm. Surface runoff, lateral flow and return flow ultimately contributes to the river flow and lost from the basin. Return flow or base flow is slower than lateral flow and surf ace runoff. The water that moves back to the atmosphere in the form of evaporation and transpiration and its value estimated at 357.4 mm

Tables:

Table 1: Sensitivity ranking of SWAT model parameters

Flow parameters	Parameter description	Rank
Alpha_Bf	Baseflow alpha factor	1
Cn2	Initial curve number II value	2
Gwqmn	Threshold water depth for base flow	3
Soil_ Z	Soil depth	4
Ch_K2	Channel hydraulic conductivity	5
Esco	Soil evaporation compensation factor	6
Gw Delay	Groun water delay	7

Surlag	Surface runoff lag time	8
Soil Awc	Available water capacity	9
Gw Revap	Revap coefficient	10

Table 2 : Calibration and Validation statistics

Statistics	Calibration period		Validation period	
	Observed flow (m3/s)	Simulated flow (m3/s)	Observed flow (m3/s)	Simulated flow (m3/s)
Mean	26.27	26.08	16.39	18.47
SD	69.99	25.68	69.99	20.29
NSE		0.88		0.9
R^2		0.96		0.99

Table 3. Water balance components of Kurumali sub basin for existing period generated from SWAT model

Year	SUR_Q (mm)	SUR_Q (RF per cent)	LAT_Q (mm)	LAT_Q (RF per cent)	GW_Q (mm)	GW_Q (RF per cent)	ET (mm)	ET (RF per cent)
1998	475.84	17	400.52	14	1933.95	69	364.77	13
1999	311.30	13	346.65	15	1732.09	72	343.70	14
2000	208.63	11	277.14	15	1339.50	73	323.34	18
2001	230.59	11	332.59	15	1593.17	74	318.06	15

CONCLUSION

In the present study, Kurumali sub basin of Karuvannur river in Thrissur district, Kerala was selected for the assessment of water balance of a watershed using swat model for water resources management**.** A very high Nash Sutcliffe Efficiency (NSE) of 0.88 and Coefficient of Determination (COD) 0.96 have been obtained for the calibration period. Corresponding NSE and COD of the model simulation for the validation period were 0.90 and 0.99. The very high NSE and COD are the clear indication of the good model prediction of the river flow. The most important water balance components considered are surface runoff (SUR_Q), lateral flow (LAT_Q), ground water flow (GW_Q) and evapotranspiration (ET). The average values for Surface runoff, lateral flow, base flow and evapotranspiration of the basin were 306.6 mm, 339.2 mm, 1649.7 mm and 337.5 mm respectively. The study pointed out that SWAT model could be a promising tool to predict water balance for the sustainable management of water resource

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