Water Balance Study on Karuvannur River Basin Using SWAT

Chithira Ajeeth and Reeba Thomas

Abstract— *Water is a precious natural resource. Its management determines its prospective capability to sustain growth and development related aspirations of the society and its balance with the need to maintain the ecological integrity of its hydrological crucible. To deal with water management issues, one must analyse and quantify the different elements of hydrologic processes taking place within the area of interest. Obviously, this analysis must be carried out on a watershed basis because all these process are taking place within individual micro watersheds. Only after understanding the spatial and temporal variation and the interaction of these hydrologic components one can scientifically formulate strategies for water conservation. To achieve this goal the choice and use of an appropriate watershed model is a must.*

Numerous integrated watershed models are available but choice of watershed development model depends upon the hydrologic components to be incorporated in the water balance.

In this study, SWAT, developed by USDA has been used to analyze and quantify the water balance of a river basin namely, Karuvannur in Kerala. It is an integrated physically based distributed watershed model and its suitability to different parts of the world has also been well established. Model uses DEM, land use, soil and climate data. Then the model has been calibrated using observed river flow data. Before the calibration, a sensitivity analysis of the model has been carried out to understand the most sensitive parameters which help in parameter reduction at the calibration phase. Manual calibration has been performed.

The calibration efficiency has been tested by Nash Sutcliff efficiency and coefficient of determination. Both these efficiency measures figured above 75% indicating very high predictive ability of the model. Time series curves of observed and simulated also showed very high similarity. In general, the model over predicted the peak flow during monsoon months. Water balance components of the basin have been simulated and it is found that the surface runoff contribution is the maximum in the river flow followed by ground water flow.

Keywords--- *Watershed Model, SWAT, Calibration, Validation, Sensitivity Analysis, Water Balance*

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I. Introduction

WATER is a precious natural resource and its management determines its prospective capability to sustain growth and development related aspirations of the society and its balance with the need to maintain the ecological integrity of its hydrological crucible. In order to keep pace with the global economic growth and industrial development, drainage basins all over the world are in the process of alteration by man. The last few decades have seen lot of changes in the field of water resources developments. In the blind run for economic development a lot of anthropogenic influences have been imposed upon the natural systems raising the question of sustainability. From the ever increasing population and the need for security, it is realized that water and land resources need to be developed, used and managed in an integrated and comprehensive manner.

A watershed is a drainage area on earth's surface from which runoff resulting from precipitation flows past a single point into a larger stream viz. a river, a lake or an ocean. Hydrology is the main governing backbone of all kinds of water movement. Understanding the hydrology of a watershed and modelling different hydrological processes within a watershed are therefore very important for assessing the environmental and economical well-being of the watershed. The water balance of a basin is the key aspect in water resources development and management programmes. The components of water balance of a basin are influenced by climate and the physical characteristics of the watershed such as morphology, landuse and soil. The relationship with landuse change is more critical. Land change unquestionably has a strong influence on global water yield. Land cover/landuse directly impacts the amount of evaporation, groundwater infiltration and overland runoff that occurs during and after precipitation events. These factors control the water yields of surface streams and groundwater aquifers and thus the amount of water available for both ecosystem function and human use [1]. River discharge worldwide has increased noticeably since 1900, and studies suggest that land change may be directly responsible for as much as 50% of this increase [2]. Understanding the relationship between the physical parameters and hydrological components are therefore 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.

Simulation models of watershed hydrology and water quality are extensively used for effective planning of water resource use and protection under changing conditions .These models can offer a sound scientific framework for watershed analyses of water movement and provide reliable information on the behavior of the system. New developments in modelling systems have increasingly relied on Geographic Information Systems (GIS) that have made large area simulations feasible, and on database management systems such as Microsoft Access to support modelling and analysis. Choice of watershed development model depends upon the hydrologic components to be incorporated in the water balance. 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. Among them, researchers have identified SWAT as the most promising and computationally efficient [3]. SWAT, one among the top most hydrological model has evolved from numerous individual models over a 30 year period and has been tested worldwide for a wide range of regions, conditions, practices and time scales [4]. Hence, in this study, ArcGIS interface of SWAT was used. Here an attempt has been made to identify the most sensitive flow parameters, to calibrate, and validate the SWAT model and to determine the important hydrologic components of the river basin with focus on water conservation and management.

II. MATERIALS AND METHODS

A. Study Area

The Karuvannur river basin lies between 10 ^{0} 15’ to 10 ^{0} 40’ North latitude and 76 ^{0} 00’ to 76 ^{0} 35’ East longitude within Thrissur and in the Western Boundary of Palakkad districts of Kerala. Karuvannur River has a drainage area of 1054 km^2, stream length 48 km. The river originates from the Western Ghats and is fed by its two main tributaries, viz., the Manali and the Kurumali. The Manali River originates from Ponmudi in the boundary of Thrissur and Palakkad districts at an elevation of + 928 m. The Chimony and Muply, the two sub tributaries of the Kurumali originate from Pundimudi at an elevation of + 1116 m. This is one of the major river basins with the actual utilizable water resources of 623 million cubic metre of which the net utilizable surface and ground water resources are 519.8 million cubic metre and 103.2 million cubic metre respectively. The average rainfall in the low land of the river basin is estimated to be 2858 mm, the midland 3011mm and the highland 2851 mm. The location map of Karuvannur river basin is shown in Figure 1.

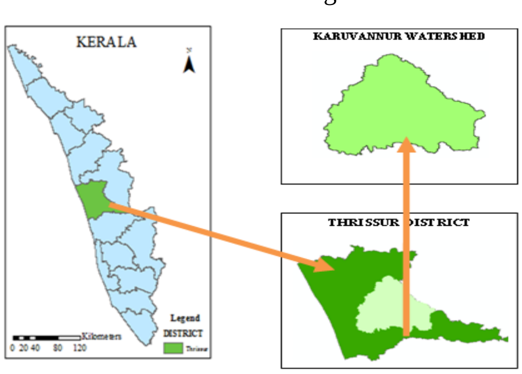

Fig 1: Location of Karuvannur Watershed

B. Data Sources

The basic spatial data needed for the Arc SWAT interface are Digital Elevation Model (DEM), soil type and land use. The data required by the model to establish the water balance equation include weather, parameters describing catchment characteristics and reservoir data. DEM was obtained from the NASA 90-meter Shuttle Topography Radar Mission (SRTM) dataset. It is freely downloadable at http://srtm.csi.cigar.org. This DEM was used to delineate the watershed and analyze the drainage pattern of the land surface terrain. The land use map was obtained from the Kerala Forest Research Institute (KFRI), Kerala, India.

The soil map for Thrissur district was also available from KFRI. This database provides data for soil mapping units with two layers (0 - 30 cm and 30 - 100 cm depth). Twelve soil units are then extracted and completed by providing additional information from literature, national soil documents and with help of SPAW model. Local weather data which includes the data such as temperature data, wind speed, relative humidity, solar radiation etc., was obtained from the Agricultural University, Vellanikkara, Kerala, India. The Karuvannur watershed includes several hydrometric stations that measure daily precipitation and daily river discharge. The observation data of 5 rain gauging stations and 1 stream gauging station in Karuvannur basin were collected.

C. Model Setup

Hydrologic modelling of the Karuvannur was carried out using the ArcSWAT interface for SWAT2009. The runoff prediction using SWAT was carried out using various input data such as topography, vegetation, soil properties and weather in the watershed. The watersheds are initially divided into subbasins, which are further divided into hydrologic response units (HRUs) based on similar land use, soil distribution, and slope. The use of sub-basins in a simulation is particularly beneficial when different areas of the watershed are dominated by land use or soils dissimilar enough in properties to impact hydrology.

SWAT separates the hydrologic cycle into two sections: the land phase and the routing phase. The land phase keeps track of the water movement from the land to the main channel in the basin while the routing phase outlines how the water transported through the channel network.

The Hydrology components of SWAT include canopy storage, infiltration, redistribution, evapotranspiration, lateral subsurface flow, surface runoff, ponds, tributary channels and return flow. Based on daily precipitation, runoff, evapotranspiration, percolation, subsurface return flow, groundwater flow, and changes in water storage, a daily water budget in each HRU is calculated.

The hydrologic cycle was simulated by the SWAT model based on the following water balance equation.

$$SW_t = SW_o + \sum_{t=1}^{t} (R_t - Q_t - ET_t - P_t - QR_t) \qquad (1)$$

Where,

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SW_t and SW_o are the soil water content at the beginning and end of a time period for which water balance equation is written (mm). R_t , Q_t , ET_t , P_t *and* QR_t are the rainfall (mm), the surface runoff (mm), the evapotranspiration (mm), the percolation (mm) and the lateral flow (mm) respectively.

Two methods for estimating surface runoff are provided in SWAT: The SCS curve number procedure (SCS, 1972) and the Green and Ampt infiltration method. In this study, the SCS method was used. The SCS curve number method estimates surface runoff from daily rainfall using initial abstractions (surface storage, interception, and infiltration prior to runoff) and a retention parameter which varies with respect to changes in soil, land use, management, and slope and soil water content. The daily surface runoff is given by

$$Q_t = \frac{(R_t - o.2S)^2}{(R_t + o.8S)} \quad (2)$$

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 is calculated as

$$S = 25.4\left(\frac{1000}{CN} - 1\right) \quad (3)$$

Where, CN is the curve number for the day. The SCS curve number is a function of the soil's permeability, land use and antecedent soil water conditions [5].

Once the surface runoff is calculated with the curve number or Green and Ampt method, the amount of surface runoff released to the main channel is calculated. Three methods have been incorporated into SWAT to estimate Potential Evapotranspiration (PET). They are the Penman- Monteith method, the Priestley-Taylor method and the Hargreaves method, of which the first one is used in this work.

Simulations are performed at the HRU level and summarized in each subwatershed. The simulated variables (water, sediment, nutrients, and other pollutants) are routed through the stream network to the watershed outlet.

SWAT requires many sets of spatial and temporal input data. As semi-distributed model, SWAT has to process, combine and analyze spatially these data using GIS tools. Therefore, to facilitate the use of the model, it was coupled with two GIS software as free additional extensions: ArcSWAT for ArcGIS and MWSWAT for MapWindow.

D. Methodology

The first step in using the SWAT model is to delineate the watershed and then divide it into multiple HRUs and sub-basins. The primary inputs for the analysis are the Digital Elevation Model (DEM), land use map and soil map for the region. The slope map is prepared from the DEM. Each map of the slope, the land use and the soil was first categorised into different groups. Then the delineated watershed is divided into (homogeneous areas) by overlaying of slope, land use and soil layers of unique combinations. These HRU are identified such that the characteristics of these layers fall into the same combination of categories. A threshold level was used to eliminate HRUs with small areas. Normally, a stream network (vector data) was *burnt* to force the generated streams to follow existing stream reaches. Burning in a stream network improves hydrological segmentation and sub watershed delineation. The model was set up as described earlier and the drainage areas both the watersheds were delineated. This resulted in the subdivision of the watersheds into 6 sub-basins in Karuvvanur river.

The simulation period can be set according to the requirement; hence, the period of simulation was fixed as 2000-2010. Subsequently, the weather sources were defined. The curve number method for the surface runoff, Penman Monteith method for potential evapotranspiration, skewed normal distribution for the generation of monthly values and a variable storage method for channel routing were selected from the available options. These were mutually processed in the GIS environment provided by the ArcSWAT.

A sensitivity analysis was initially performed for the entire data. Subsequently, calibration was carried out for years 2002-2005, to evaluate the performance of SWAT model in simulating steamflow at Karuvannur watershed.

III. Results and Discussions

The sensitivity analysis reveals that curve number (CN) is the most sensitive parameter, followed by alpha base flow factor (Alpha_Bf) and threshold water depth for base flow (Table.1). This result supports those found by many similar studies confirming that these three parameters are the crucial sensitive parameters for water balance. Calibration was performed on 5 parameters.

Running SWAT model with the specified optimal values allow measuring the performance of the model. This is done by comparing the observed and simulated stream flow at the Karuvannur gauging station for both the calibration and validation periods.

Table 1: Sensitivity analysis result of streamflow at Karuvannur Watershed

Flow Parameter	Parameter Description	Rank
Cn2	Initial curve number (II) value	1
Alpha_Bf	Baseflow alpha factor	2
Gwqmn	Threshold water depth for base flow	3
Esco	Soil evaporation compensation factor	4
Ch_K2	Channel hydraulic conductivity	5
Gw_Delay	Groundwater Delay	6
Surlag	Surface runoff lag time	7
Sol_Awc	Available water capacity	8
Sol_Z	Soil depth	9
Gw_Revap	Revap coefficient	10

The simulated discharges were compared to the observed discharge on monthly and daily time step. The graphical comparison of the simulated to the observed discharge, for the calibration period are illustrated in Fig.2 for monthly time step similarly for validation period, the Fig.3 shows the simulated and observed monthly discharges.. Visual inspection of these figures clearly indicates that during calibration and validation periods some peaks are over or under predicted, for significant rain events (rain greater than 100mm) peaks were closely

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predicted. As can be seen from these figures, on monthly basis, during the calibration and validation years the model was able to reproduce the trend of the observed runoff (Fig.2 and Fig.3).

Furthermore the calibration accuracy was checked by calculating Nash-Sutcliffe Efficiency (NSE) and Coefficient of Determination (R^2). The model was validated using the same indices giving similar results to those of the calibration. The results of these tests proved to be adequate and are summarized in Table 2.

Nash-Sutcliffe Efficiency (NSE) and Coefficient of Determination (R^2) for monthly discharge was computed during calibration period. The NSE and R^2 on monthly data series were 0.76 and 0.82 respectively which is indicative of the good performance of the model.

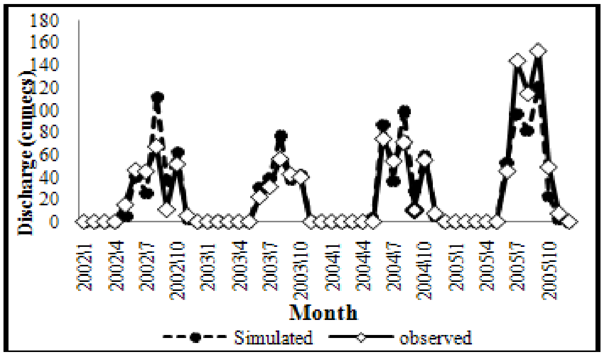

Fig.2: Monthly calibration plot

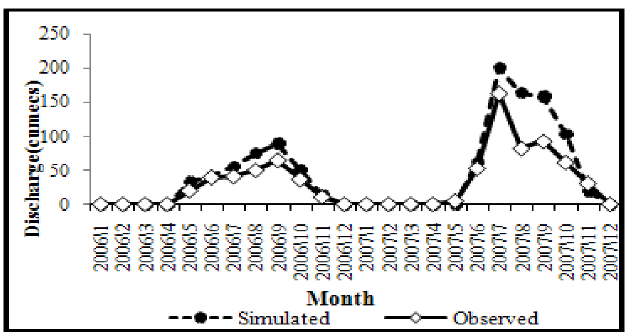

Fig.3: Monthly validation plot

Table 2: NSE and R^2 indices for Model Evaluation in Monthly Basis

VALUE	BEFORE CALIBRATION		AFTER CALIBRATION		VALIDATION	
	NSE	R^2	NSE	R^2	NSE	R^2
Monthly	0.58	0.67	0.76	0.82	0.79	0.86

Once the model was made fit for the study area by performing sensitivity analysis and calibration, the hydrologic components in the watershed was estimated. Table 3.gives the average values of water balance components in the area.

Table 3: Average values of hydrologic components

Hydrologic components	Value in mm	% of precipitation
Surface Runoff	1116.33	38.9
Lateral Flow	164.78	5.7
Ground water Flow	948.62	33
Deep Recharge	51.22	1.8
Evapo-transpiration	558.10	19.5
Loss	7.34	0.002
Precipitation	2866.10	100

Relative percentage of each component to total rainfall was calculated and in Fig.4. It reveals that surface runoff dominates the area. Major portion of precipitation contributes to surface runoff followed by ground water flow.

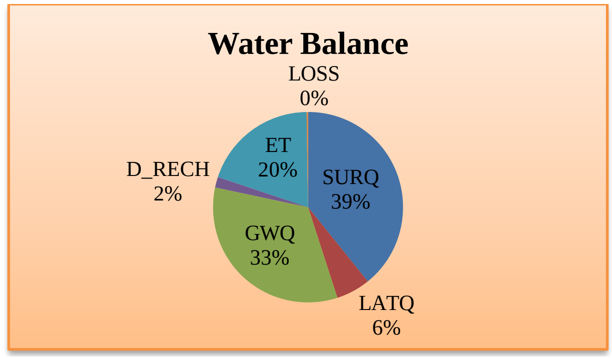

Fig. 4: Pecrentage of Hydrologic Components Relative to Precipitation

IV. Summary and Conclusion

In conclusion, SWAT model was successfully calibrated in the Karuvannur watershed. The model produced good simulation results for monthly average stream flow as for the other water balance components. The evaluation of the model performance is carried out successfully with the recommended statistical coefficients. In this context, the comparison of observed and simulated flow stream revealed a Nash-Sutcliffe coefficient and R^2 superior to 0.7 for both calibration and validation periods.

The calibrated model can be well used in Karuvannur watershed to assess and handle other watershed components responses such as the impacts of land and climate changes on the water resources as well as the water quality and the sediment yield.

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