RESEARCH PAPER | International Journal of Agricultural Engineering | Volume 7 | Issue 1 | April, 2014 | 198–202

A semi–distributed water balance model for Walayar sub basin using SWAT model

K. BALATHANDAYUTHAM AND **C. MAYILSWAMI**

Received : 25.01.2014; **Revised :** 05.03.2014; **Accepted :** 17.03.2014

See end of the Paper for authors' affiliation

Correspondence to :

K. BALATHANDAYUTHAM
Department of Soil and Water Conservation Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, COIMBATORRE (T.N.) INDIA
Email : balathandayutham03@gmail.com

ABSTRACT : Groundwater is a dynamic and replenishesable natural resource but in hard rock terrains availability of groundwater is of limited extent. In India, 65 per cent of the total geographical area is covered by hard rock formations. In this study, a spatially semi distributed water balance model was developed to simulate mean monthly hydrological processes using land use, soil texture, topography, and hydrometeorological data as input parameters in the Walayar sub-basin, a semiarid region of Tamil Nadu in India. The spatially and temporal semi-distributed water balance modelling system provided the framework, containing code to simulate all major hydrological processes, including actual evapotranspiration estimates, to simulate the impacts of climate change in Walayar sub-basin, Tamil Nadu, India, under historical (1983–2012). The water balance model is developed using SCS – CN (Soil Conservation Service – Curve Number) model to derive the runoff component and FAO-PM (Food and Agriculture Organization – Penman Monteith) model to derive the evapotranspiration component spatially and temporal with the help of remote sensing and GIS techniques. The results of the study indicate that the overall rate of groundwater recharge is predicted to decrease as a result of climate change. The higher intensity and frequency of precipitation will also contribute significantly to surface runoff, while global warming may result in increased evapotranspiration rates. While many previous climate change impact studies have focused on the temporal changes in groundwater recharge, our results suggest that the impacts can also have high spatial variability.

KEY WORDS : Climate change, Water balance, SWAT model, Ground water recharge

HOW TO CITE THIS PAPER : Balathandayutham, K. and Mayilswami, C. (2014). A semi–distributed water balance model for Walayar sub Basin using SWAT model. *Internat. J. Agric. Engg.*, **7**(1) : 198-202.

Groundwater studies require estimates of the quantity of water moving downwards from the soil zone which represent the potential recharge. Any methodology selected for the estimation of potential recharge must be applicable in a wide variety of climatic and hydrological situations. The important physical processes must be represented adequately. Unnecessary complexities should be avoided with parameter values based on readily available field information. Estimates are usually required for several decades. There are several detailed reviews of methods for estimating recharge.

Recent studies (e.g. Kliwa, 2003; Fürst *et al*., 2007) show that there are seasonal trends in precipitation and temperature, which affect the runoff conditions, as summarized by the mean annual flow, seasonal distribution of flows and the flow duration curve. Identification of the net groundwater recharge is essential for groundwater modelling and water resources management. The calculation of the net groundwater recharge is a big challenge for the hydrologist since there is no specific method to find out the net recharge reliably. There are so many methods for quantification of groundwater recharge from rainfall. Each method has its limitations in terms of applicability, accuracy and complexity.

Hartono (2005) estimated the groundwater recharge for Chicot aquifer (State of Louisiana, USA) using a GIS-based net water balance technique that incorporates rainfall, soil properties, runoff, soil moisture, storage, and evapotranspiration to estimate recharge rates across the aquifer. Results show how seasonal and long-term variations in agricultural demand and rainfall can significantly impact the recharge. Jasrotia *et al.* (2009) has performed a water balance study using the Thornthwaite and Mather model with the help of Remote Sensing and GIS for finding out the moisture deficit and moisture surplus of a watershed. Tilahun and Merkel (2009) has used a spatially distributed water balance model WetSpass to simulate longterm average recharge using land use, soil texture, topography, and hydrometeorological parameters in a semiarid region of Ethiopia.

Quantifying the spatial and temporal distribution of natural groundwater recharge is usually a prerequisite for effective groundwater modeling and management. As groundwater flow models become increasingly utilized for management decisions, there is an increased need for simple and practical methods to delineate recharge zones and quantify recharge rates. Existing models for estimating recharge distributions are data intensive, require extensive parameterization, and take a significant investment of time in order to establish (Dripps and Bradbury, 2007).

METHODOLOGY

Study area:

Walayar sub basin is one of the three sub-basins in Parambikulam-Aliyar-Palar basin situated in Coimbatore district, Tamil Nadu, India (Fig. A) and lies between 10°40’00” to 10°20’00” N latitude and 76°50’00” to 77 °20’00” E longitude. It spread over an area of 877.49 km^2. In Walayar sub-basin, there are two streams originating one at the north eastern part of plain is Koduvadi Aru, starts at an elevation of 445 m above MSL and Walayar river at the northern part of the basin area ie. in the Balampatti Block Reserved Forest and hilly area at an altitude of 1135 m above MSL. Walayar and Koduvadi Aru are flowing in south and southwest directions. The major crop grown in this sub- basin area is coconut, sugarcane, banana, mango, fodder, paddy, groundnut, cotton, vegetables, pulses, tomato and maize.

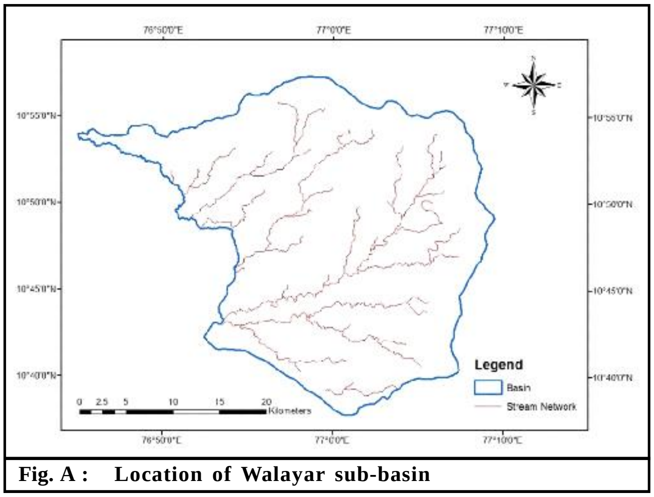

Fig. A : Location of Walayar sub-basin

SWAT model description and model setup:

For running the SWAT model, a Digital Elevation Map of the study region was derived from STRM 90 m elevation dataset given in Fig. B. Elevation in the Walayar sub-basin ranged from 168 to 1192 m above MSL. Automatic delineation of sub-basin is done to explain the spatial variability of various input parameters. In this study the Walayar sub-basin is located in the south western part of the Peninsular India and covers area in Kerala and Tamil Nadu States. Information on soil was based on the soil map at 1: 50,000 scales obtained from the Remote Sensing Unit of Tamil Nadu Agricultural University, Coimbatore. Though Walayar sub-basin has a variety of soils, majority of the area has sandy clay loam and sandy loam soils. Sizable area also represents sandy clay and clay soils given in Fig. C. The Land use data was obtained from Indian Space Research Organisation (ISRO), Bangalore given in Fig. D. The entire Walayar sub-basin was divided into 69 micro-basins for the spatial aggregation given in Fig. E. Each micro-basin was further divided into hydrological response units (HRUs) which have unique combination of soil, slope, land use and weather. For each land use in every HRU, management practices including time of sowing, harvest, intercultural operations, different inputs used were specified.

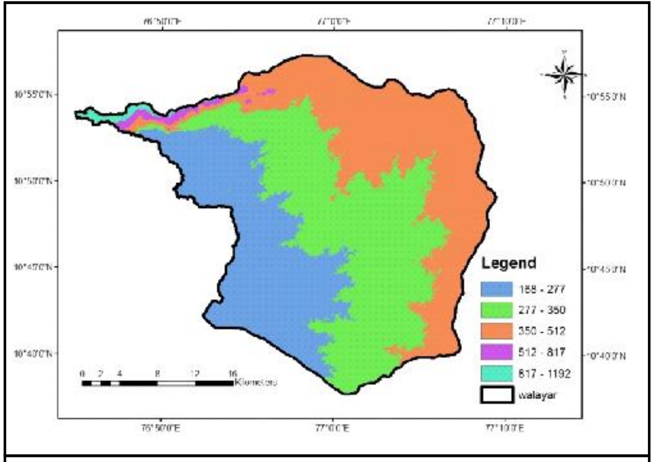

Fig. B : Elevation map of the Walayar sub-basin

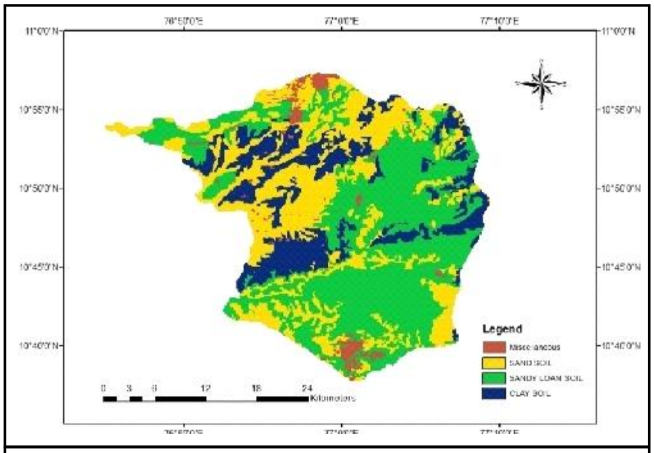

Fig. C : Soil map of the Walayar sub-basin

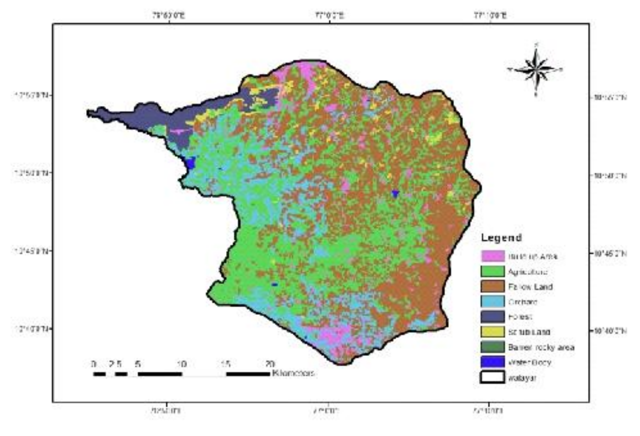

Fig. D : Land Use map of the Walayar sub-basin

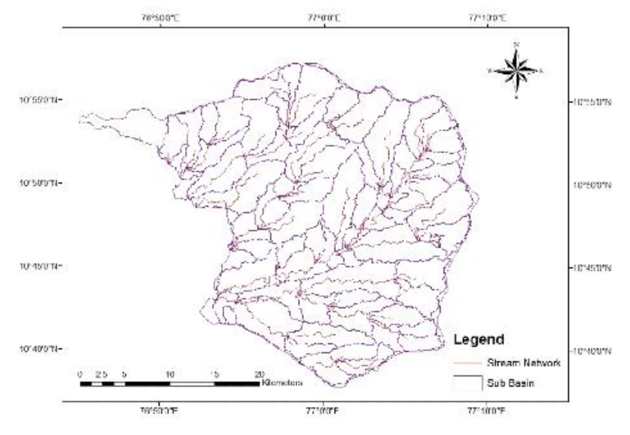

Fig. E : Delineation of Walayar sub-basin

Climatic data is one of the important components that drive the hydrologic model. Observed daily rainfall and temperature data from 1983 to 2012 were obtained from Coconut Research Station, Tamil Nadu Agricultural University, Aliyar Nagar and from India Meteorological Department. In the absence of other daily weather data on solar radiation, wind speed and relative humidity, these weather parameters have been generated using long term statistics though the weather generator in built in the SWAT model. The derived runoff and actual evapotranspiration on a monthly scale in each cell is to be used for SWAT model calculating the water balance in each cell. The percolation and deep percolation components are not considered separately in the model development to avoid complexity. The water balance can be found out from equation (1) as

$$\mathbf{GWR = P - Q - actual\ ET - Soil\ water\ content} \tag{1}$$

where

P is precipitation (mm),

Q is the surface runoff (mm),

ET is the actual evapotranspiration (mm),

GWR is the ground water recharge (mm).

RESULTS AND DISCUSSION

The experimental findings obtained from the present study have been discussed in following heads:

Current hydrology of Walayar sub-basin:

Four hydrological components are considered, *i.e.*, precipitation, actual evapotranspiration (ET), runoff, soil water content and balance closure. The term 'balance closure' includes groundwater recharge, change in soil moisture storage in the vadose zone and model inaccuracies. The annual hydrological parameters simulated by SWAT (for 30 years from 1981 to 2000) are presented in Table 1. Fig. 1 show the mean decadal water balance of the whole sub-basin. The inter annual rainfall variation in Walayar sub-basin is high which ranges between 396.2 mm and 1009.3 mm with a mean value of 677.77 mm. The mean annual soil water content and water yield is 251.66 mm accounting for 35% of annual average rainfall. Mean annual evapotranspiration is 402.7 mm which is 55.78% of mean annual average precipitation. The atmospheric moisture demand (PET) of the basin is 1233.05 mm, indicating the need of water from external / underground sources for successful crop production. However, there was a large variation in the spatial distribution of these components. Precipitation, actual ET, runoff and soil water content were found to be higher in the forested and mountainous upper areas. In the upper sub-basins, water yield is higher than ET. However, in some of the lower sub-basins dominated by agriculture, ET values were higher than water yield. Water balances from the lower part of the catchment, containing irrigated areas, are affected by water regulation through barrages, dams and canals. The large network of canals is transferring water from one sub-basin to irrigate crops in another sub-basin. Therefore, it is difficult to determine the accuracy of the runoff calculations from each sub-basin.

The simulation results obtained in the present study show that the spatial variation of the availability of water in the basin, on a monthly time scale, is useful for decision making and the effective utilization of water. The results obtained here compare favourably with other similar studies, done by Voudouris (2007) and Asefa *et al.* (1999) particularly considering the amount and quality of the input data.

Conclusion:

The distribution of water balance components is a primary concern for forests and their environment in the future. Based on the observed rainfall and other hydrogeological data, the water balance of the basin was modelled. The water balance components in a monthly time scale utilizing the spatial variability of the catchment characteristics were evaluated

Table 1 : Yearly water balance parameters of Walayar sub-basin

Year	Precipitation (mm)	Runoff (mm)	Soil water content (mm)	ET (mm)	Groundwater recharge (mm)
1983	697.34	23.83	34.81	359.51	251.22
1984	668.12	15.51	34.49	411.93	180.53
1985	629.54	12.13	43.62	389.92	162.92
1986	542.06	11.35	36.06	334.19	138.84
1987	729.70	30.86	33.66	428.45	208.40
1988	664.34	19.92	14.89	392.17	213.89
1989	716.50	8.74	37.77	511.89	133.69
1990	566.24	18.58	28.17	371.15	129.05
1991	570.36	16.18	12.9	407.24	114.58
1992	720.77	22.69	23.18	394.73	248.11
1993	632.28	23.93	41.12	386.11	160.39
1994	743.74	49.23	17.21	412.4	234.96
1995	396.02	3.51	16.52	338.54	23.93
1996	785.56	17.5	22.87	445.27	270.67
1997	1009.26	122.29	27.63	517.01	305.28
1998	786.60	149.79	17.37	358.11	233.99
1999	747.42	27.01	19.81	435.12	236.53
2000	666.68	15.02	26.34	429.28	172.38
2001	551.84	7.24	41.84	386.67	99.83
2002	451.08	3.19	39.71	351.78	40.89
2003	491.52	9.04	11.78	344.33	110.01
2004	648.26	32.92	24.5	383.61	182.48
2005	908.50	20.18	26.12	552.85	275.78
2006	758.46	149.79	17.37	358.11	205.85
2007	700.98	52	17.39	403.35	203.03
2008	654.18	87.64	26.37	352.36	166.12
2009	568.36	18.58	28.17	371.15	131.17
2010	624.60	16.99	14.87	366.03	204.95
2011	869.20	77.32	19.97	473.65	265.21
2012	783.9	68.13	31.37	414.14	242.56

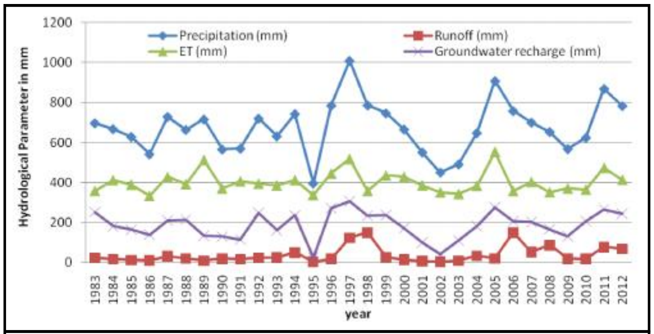

Fig. 1 : Water balance of Walayar sub-basin

using the water balance model. The inter annual rainfall variation in Walayar sub-basin is mean value of 677.77 mm. The mean annual soil water content and water yield is 251.66 mm accounting for 35% of annual average rainfall. Mean annual evapotranspiration is 402.7 mm which is 55.78% of mean annual average precipitation. The atmospheric moisture demand (PET) of the basin is 1233.05 mm, indicating the need of water from external / underground sources for successful crop production. The results are useful in agricultural planning, recharge by rain water harvesting, groundwater modelling, vulnerability studies, etc. in the area. It can be found that using input data at a higher spatial resolution, will further improve the performance of the model. Further studies on the impacts of climatic changes on the water balance components is poposed.

Authors' affiliations:

C. MAYILSWAMI, Water Technology Centre, Tamil Nadu Agricultural University, COIMBATORE (T.N.) INDIA

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