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International Journal of Recent Scientific Research
Vol. 4, Issue, 4, pp.371 -375, April, 2013

ISSN: 0976-3031

International Journal of Recent Scientific Research

RESEARCH ARTICLE

A COMPARATIVE STUDY ON THE PERFORMANCE OF SWAT AND APEX MODEL FOR SIMULATING WATER YIELD IN DUDHI MICRO WATERSHED IN MADHYA PRADESH, INDIA

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ARTICLE INFO

Article History:

Received 12th, February, 2013
Received in revised form 15th, March, 2013
Accepted 27th, March, 2013
Published online 30th April, 2013

Key words:

SWAT, APEX, GIS, Subbasin, discharge

ABSTRACT

A modeling exercise is performed to test and compare the ability of SWAT and APEX watershed models for implementation in watershed management at Micro-watershed level. Data obtained from Regional Research Laboratory Bhopal in Madhya Pradesh, India for Dudhi watershed were processed and converted to SWAT required format using GIS technologies. Watershed delineation application of AVSWAT were used to demarcate subbasins and to generate the topographic variables as required by APEX to build the subarea file, indicating routing mechanism as used for the study area. The SWAT and APEX models were run independently with the set up of input data for individual model and simulated discharge by both the models were compared with observed discharge data for the period 20/7/2000 to 30/9/2000 (for the period which the data on observed discharge were available). Results indicate that both SWAT and APEX models were able to replicate the daily variation in observed flow for the study period. SWAT underestimated the observed flow during peak flow period and over estimated the observed flow during low flow period. In contrast APEX overestimated the observed flow during peak flow period and underestimated the observed flow during low flow periods. R^2 values obtained from scatter diagram plotted between observed and simulated flow for both the models indicate that APEX model is able to simulate the flow with slightly greater degree of confidence as compared to that with SWAT. Therefore while both model can be applied for watershed management in the study area but ability of the APEX model to simulate water balance at higher spatial resolution i.e. at plot level makes it more appropriate tool for watershed management at field or micro watershed level.

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INTRODUCTION

A watershed model simulates hydrologic processes in a more holistic approach, compared to many other models which primarily focus on individual processes or multiple processes within a water body without full incorporation of watershed area (Oogathoo, 2006). Advances in the understanding of physical, chemical, and biological processes influencing water quality and quantity, coupled with improvements in the collection and analysis of hydrologic data provide opportunities for significant innovations in the manner and level with which watershed-scale processes may be explored and modeled. The utility of hydrological modeling for generation of crucial information such as water and sediment yield for planning and management of the watershed management program is being increasingly recognized now. A number of simulation models have been developed to evaluate water quantity and quality parameters affected by agricultural land management at both field and watershed scale. Widely used Watershed scale models include storm event based AGNPS (Agricultural Non-Point Source Pollution Model) and continuous daily time step model SWRRB (Simulator for Water Resources in Rural Basins).

Expansion of SWRRB model's capacities to facilitate more sub-basins and sophisticated routing structure resulted in a new watershed scale model SWAT (Soil and Water Assessment Tool) (Arnold *et al.,* 1998). Widely used field scale models include CREAMS (Chemicals, Runoff, Erosion from Agricultural Management Systems), EPIC (Erosion-Productivity Impact Calculator), and GLEAMS (Groundwater Loading Effects of Agricultural Management System). Expansion of EPIC model capability to simulate multi field routing for use in whole farm/small watershed management resulted in the development of APEX (Agricultural Policy/Environmental Extender) model (Williams and Izaurralde, 2006).

The utilization of GIS technology in watershed modeling has brought great value and presents future potential benefits for watershed managers. To date, watershed modelers have been able to capture the key hydrological behaviors of many watershed systems. Despite the complexity and uncertainty of various watershed processes, many engineering-based models have been successfully calibrated, verified, and applied by decision makers. Our ability to model hydrologic processes with greater accuracy, and at finer spatial and temporal resolution is continuing to improve with increased use of

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remotely sensed data (e.g., satellite observations), increased computational capacity, and improvements in GIS and database management systems and availability of meteorological information for simulating the water balance components. In India GIS based SWAT model has been widely tested and recognized as reliable tool for watershed management at watershed level (Gosain *et al,* 2004, Gosain *et al.,* 2005). However implementation of SWAT at microwatershed or filed level is not yet completely tested with greater degree of confidence. One of the widely used field scale model which simulate the water quality and quantity at plot level is APEX (Williams and Izaurralde, 2006). APEX model is now increasingly applied in different part of world to simulate the impact of different conservation practices at plot level (Wang *et al.,* 2006; Saleh *et al.,* 2007, Santhi *et al.,* 2008). In the present study an attempt has been made to test and compare the suitability of SWAT and APEX model for implementation at micro watershed level. Details methodology and data used for the purpose is described in the following section.

MATERIALS AND METHODS

Modeling Tools

The SWAT Model

The SWAT model is a basin-scale distributed hydrologic model. It was developed to quantify the impact of land management practices in large, complex catchments (Arnold *et al.,* 1998). SWAT is capable of accepting output data from other simulation models. SWAT operates on a daily time step and allows a basin to be divided into subbasins based on topography to incorporate spatial details. Each subbasin is further divided into hydrological response units (HRUs), which are unique combinations of soil and land cover. Individual HRUs are simulated independently, area weighted, and added for each subbasin and then routed through a stream network to the basin outlet. HRUs allow more spatial detail to be included by representing more land use and soil classifications in the landscape in a computationally efficient manner. The HUMUS project (Srinivasan *et al.,* 1998) used SWAT to model 350 USGS 6-digit watersheds in the 18 major river basins in the U.S. The revised HUMUS/SWAT (Santhi *et al.,* 2005) modeling framework with updated databases for the 18 major river basins was used for the CEAP cropland national assessment, in which the cultivated cropland and CRP land are simulated using the APEX model. The reason for applying SWAT model in present study has been two folds. The first one is to GIS interface of the SWAT to carry out the automatic delineation at the watershed level which is not available in the APEX, and the second one is that this shall give opportunity to evaluate the impact of bringing the natural areas under cultivation on its hydrology.

The APEX Model

The APEX model is an integrated dynamic tool that is capable of simulating extensive land management strategies, such as nutrient management practices, tillage operations, and alternative cropping systems on the field, farm, or small watershed scale (Arnold *et al.,* 1998). It can be configured to simulate filter strip impacts on pollutant loss from upslope fields, intensive rotational grazing scenarios depicting movement of cows between paddocks, impacts of vegetated grassed waterways in combination with filter strip, land application of manure, as well as removal of manure from livestock feedlots or waste storage ponds. APEX operates on a daily time step. A detailed theoretical description of APEX can be found in Williams and Izaurralde (2006). The APEX model was selected for the CEAP field-level cropland modeling due to its flexibility and features. For example, field units within APEX have spatial relationships and can be routed at the field scale, which provides for physically based simulation of conservation practices such as filter strips, terraces, and waterways. In addition, the APEX crop growth component enables simulation of mixed stands with plant competition for light, water, and nutrients. APEX also simulates detailed management practices related to farm animal production, rotational grazing, and wind erosion. APEX enables dynamic soil layers associated with soil erosion and removal of eroded material, and it provides eight options (including RUSLE 2) for estimating water erosion. APEX simulates tillage with the functions for mixing nutrients and crop residue, converting standing residue to flat residue, changing bulk density and subsequent settling after tillage, and speeding mineralization. APEX features an improved soil carbon cycling routine that follows the Century model (Parton *et al.,* 1994; Vitousek *et al.,* 1994). APEX has also manure management with automatic application from a stockpile or a lagoon, and simulates manure erosion from feedlots and application fields. APEX has its own data bases for weather simulation, soils, crops, tillage, fertilizer, and pesticides. Convenient interfaces are available for assembling inputs and interpreting outputs. Additional data required for setting the model run are daily weather data on Rainfall, Maximum and Minimum Temperature, solar radiation, relative humidity and wind speed, Long term monthly weather statistics to generate daily data (if daily weather data is not available), Land use and management data, Topographic data to built the flow routing configuration

Study Area

SWAT and APEX models have been applied to Dudhi micro watersheds in Raisen district of Madhya Pradesh. The Dudhi river is a tributary of the Bina River, originate near Dabari village, Silwani block of Raisen district. The catchment area of Dudhi watershed is about 5.989 Sq. Km. and it depicts third order drainage network. Required data to set the run for both the models for Dudhi Micro-watershed were obtained from RRL Bhopal. .

Preparation for SWAT Model Run

Input Data

The following data have been made use of under the static and dynamic categories of data.

Static Data

- Contours
- Drainage Network
- Dabri - Rain gauge and meteorological station with its location
- Land use classification
- Soil maps and associated soil characteristics

Dynamic Data

Quantitative daily Rainfall for Dabri rain gauge station with continuous daily data for the period 1997 to 2001. Other daily weather data were generated from their long term statistics using weather generator

Pre-Processing of Input Data

All the above data has been processed in the form of digitization and putting the same together in a geo-referenced form to create the base for the potential framework.

Contour Theme

- The Figure1 depicts the contours of the study area Dudhi and its associated untreated Bewas watersheds. In general the elevation ranges from 600 m to 700 m, although there is a very small area which has steep slope. The two watersheds belong to two different drainage systems and share a ridge separating the two drainage systems

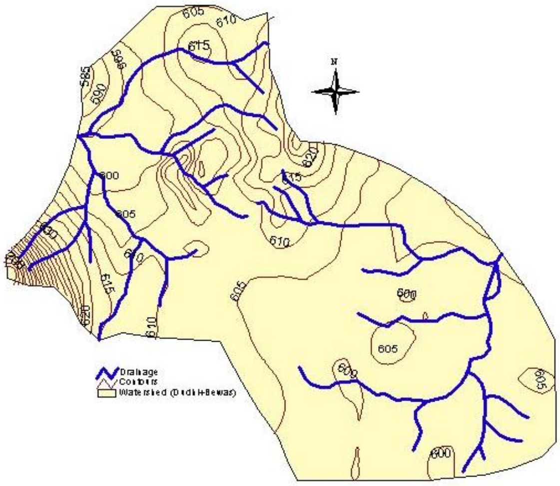

Figure1 Contours layer with 5 m interval for Dudhi and Bewas watershed Digital Elevation Model (DEM)

A DEM is an array of numbers that represent the spatial distribution of elevation above some datum. It represents a topographic surface in terms of a set of elevation values measured at a finite number of points. The vector map of contour lines (from topographic maps) are converted to raster format (Grid) before the surface is interpolated. Grids are especially suited to representing geographic phenomena that vary continuously over space, and for performing spatial modeling and analysis of flows, trends, and surfaces such as hydrology. Raster data records spatial information in a regular grid or matrix organized as a set of rows and columns. Each cell within the grid contains a number representing a particular geographic feature such as soil type, elevation, land use, slope, etc. Interpolation methods are applied to transform the contour data into a DEM i.e. from the point elevation, surface is interpolated for the elevation value for a cell, using the surrounding points in a point theme. This raster DEM contain information to determine general patterns of drainage and watersheds. The DEM generated using contours of the study area is shown in Figure 2.

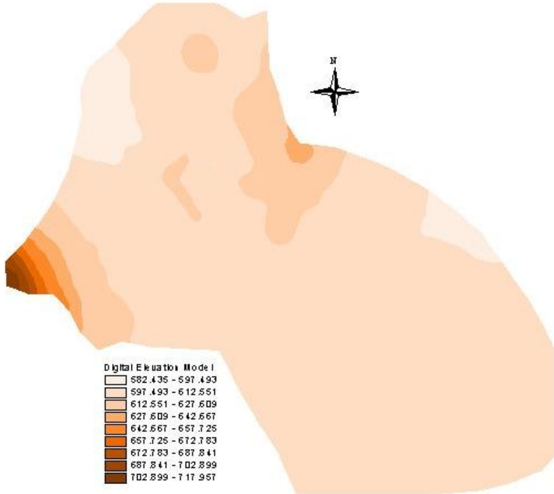

Figure 2 Digital Elevation Model of the Dudhi and Bewas watershed - 5 m resolution

Delineation of Drainage Network and subarea

Drainage Network and subarea were generated for Dudhi watershed only chosen as study area from the above DEM using watershed delineation application of AVSWAT using a threshold of 50 hectare and are shown in figure 3.

Land Use and Soils of the Study area

Figure 4 shows Land use and soil characteristics for study are**a.** Important soil properties required for the model are given in Table 1

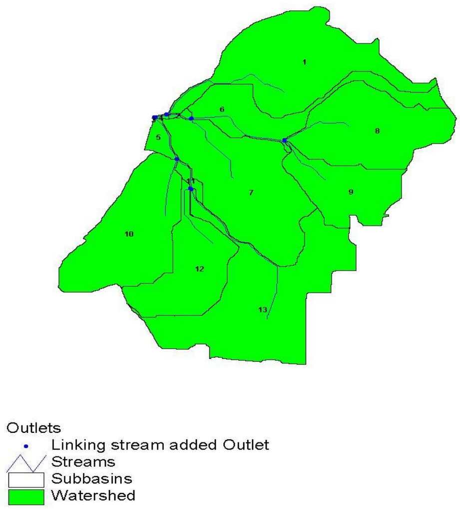

Figure 3: Generated Subarea and Drainage Network for Dudhi watershed

Preparation for APEX Model Run

APEX does not utilize GIS directly for watershed delineation therefore drainage network and subarea as delineated by AVSWAT2000 as shown in figure 3 ware also used for setting flow routing configuration of APEX. Generated topographic variables were used to built the sub area file of APEX, indicating routing mechanism as used for present watershed. Other input files of APEX were developed using the formatting instructions as given in model program using a

Table 1 Description of soil units in the Dudhi watershed

Dudhi								
Soil Type	**Area(ha)**	**% area**	**Properties**					
Typic Ustrothents	127.96	30.91	Depth	Sand	Silt	Clay	Bulk Density	Oraganic Carbon
			80	26.2	32.8	41	1.62	1.48
			180	21.5	32	46.5	1.63	1.09
			550	Weather Parent Material				
Vertic Ustrochrepts	185.00	44.69	Depth	Sand	Silt	Clay	Bulk Density	Oraganic Carbon
			180	22.8	29.4	47.8	1.65	0.69
			430	20.8	33.4	45.8	1.66	0.34
			780	24.8	33.4	41.8	1.69	0.24
			1010	22.8	33.4	41.8	1.72	0.14
			3500	21.1	29.1	49.8	1.73	0.07
Lithic Ustrothents	101.01	24.4	Depth	Sand	Silt	Clay	Bulk Density	Oraganic Carbon
			3500	72.6	9.1	18.3	1.54	1.56

DOS editor and the values for each parameter were entered manually. Subarea file showing the routing configuration for APEX were also prepared manually for the drainage network shown in figure 3

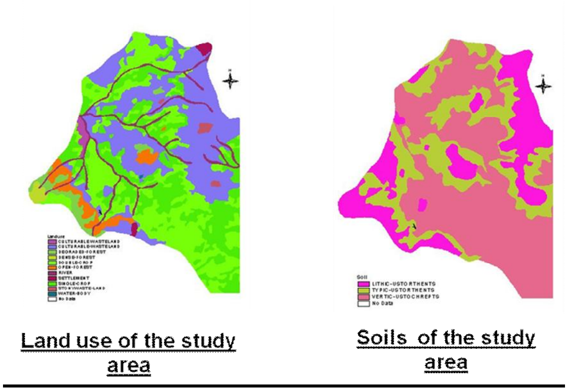

Figure 4: land Use and Soil map of Study area

RESULTS AND DISCUSSIONS

The SWAT and APEX models were run independently with the set up of input data for individual model as described in the preceding section Simulated discharge by both the model were compared with observed discharge data for the period 20/7/2000 to 30/9/2000 (for the period which the data on observed discharge were available). Comparison of Daily simulated Water Yield with APEX and SWAT against observed Yield (for the period where observed data was available) along with rainfall and scattered diagrams showing R^2 values between Simulated and Observed Yield for APEX and SWAT separately are shown in following Figure 5 and Figure 6 respectively

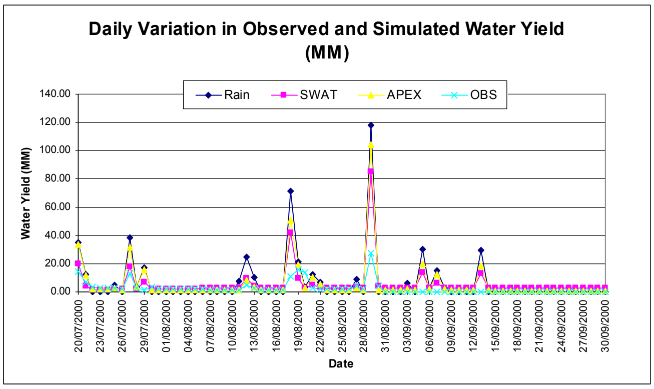

Figure 5 daily variations in simulated and observed flow

Figure 5 indicate that both SWAT and APEX model have been able to replicate the daily variation in observed flow for the study period. SWAT is underestimating the flow during peak flow period and over estimating the flow during low flow period. In contrast APEX is overestimating the flow during peak flow period and underestimating the flow during low flow period

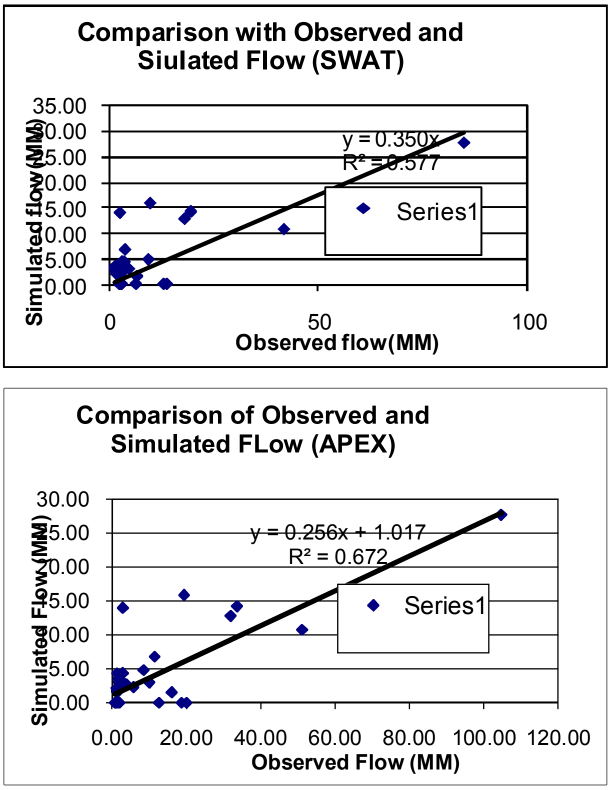

Figure 6 Scattered Diagram Showing the Comparison of SWAT and APEX Simulated Flow with the observed flow

Overall ability of both the model to simulate the water balance in the study area is indicated in figure 6. Figure 6 indicate that both models have been able to simulate the observed water yield in the study area as indicated by R^2 value in scattered diagram. However APEX model is able to simulate the flow with slightly greater degree of confidence as compared to that simulated with SWAT. Therefore while both model can be applied for watershed management in the study area but ability of the APEX model to simulate water balance at higher spatial resolution i.e. at plot level makes it more appropriate tool for watershed management at field or micro watershed level.

CONCLUSIONS

A simulation exercise is performed to test the ability of SWAT and APEX watershed models for implementation in watershed management in India. Both SWAT and APEX model have been able to replicate the daily variations in observed flow for the study period. However APEX model is able to simulate the flow with slightly greater degree of confidence as compared to that simulated with SWAT. Therefore while both model can be applied for watershed management in the study area but the ability of APEX model to simulate water balance at higher spatial resolution i.e. at plot level makes it more appropriate tool for watershed management at field or micro watershed level.

Acknowledgment

Authors are highly thankful to the official of RRL Bhopal for providing the required data for the study areas.

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