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RESEARCH ARTICLE

Evaluation of SWAT sub-daily runoff estimation at small agricultural watershed in Korea

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Abstract A study was undertaken for the prediction of runoff flow from 0.8 ha field-sized agricultural watershed in South Korea using Soil and Water Assessment Tool (SWAT) sub-daily. The SWAT model with sub-daily configuration predicted flow from the watershed within the range of acceptable accuracy. The SWAT sub-daily simulations were carried out for a total of 18 rainfall events, 9 each for calibration and validation. Overall trend and extent of matching simulated flow for the rainfall events in 2007–2008 with measured data during the calibration process were coefficient of determination (R^2) value of 0.88 and Nash and Sutcliffe Efficiency (E_{NS}) value of 0.88. For validation, R^2 and E_{NS} values were 0.9 and 0.84, respectively. Whereas R^2 and E_{NS} values for simulation results using daily rainfall data were 0.79 and -0.01, respectively, that were observed to be out of acceptable limits for the model simulation. The importance of higher time resolution (hourly) precipitation records for flow simulation were evaluated by comparing R^2 and E_{NS} with 15 min, 2 h, 6 h and 12 h precipitation data, which resulted in lower statistics with increases in time resolution of precipitation data. The SWAT sub-daily sensitivity analysis was performed with the consideration of hydraulic parameter and was found as in the rank order of CN2 (curve number), ESCO (soil evaporation compensation factor), GW_DELAY (ground water delay time), ALPHA_BF (base flow alpha factor), GWQMN (a threshold minimum depth of water in the shallow aquifer required for return flow to occur) , REVAPMN (minimum depth of water in shallow aquifer for re-evaporation to occur), LAT_TIME (lateral flow travel time) respectively. These sensitive parameters were evaluated at 10% higher and lower values of the parameters, corresponding to 70.5% higher and 23.2% lower in simulated flow out from the SWAT model. From the results obtained in this study, hourly precipitation record for SWAT sub-daily with Green-Ampt infiltration method was proven to be efficient for runoff estimation at field sized watershed with higher accuracies that could be efficiently used to develop site-specific Best Management Practices (BMPs) considering rainfall intensity, rather than simply using daily rainfall data.

Keywords Soil and Water Assessment Tool (SWAT), sub-daily simulation, runoff, rainfall

1 Introduction

A watershed is one of the potential natural resources like forest resources, arable land, water, etc. to mankind. As the earth's population is growing rapidly and more stress has been put on watershed resources to support the increased population. This stress leads to agricultural intensification and deforestation resulting in serious qualitative and quantitative harms to water resource both on regional and global scale. Watershed management to secure water resource is always research objective with accurate prediction of runoff and pollutant contaminants. Watershed modeling with Geographic Information System (GIS)

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application has been widely used to mimic real processes (topography, soil, land use, land cover, etc.) occurring at the watershed. Furthermore, watershed models are considered as holistic approach in terms of cost and time for the assessment of pollutant loads and simulation of watershed processes under various management practices [1]. Numerous watershed models have been developed to assist in understanding hydrologic systems and pollutant loadings. These models range from simple screening and planning models, such as USLE [2], to complex hydrological assessment models, such as [3–14] CREAMS, ANSWERS, SPNM, EPIC, SWRB, GLEAMS, NAPRA WWW, WEPP, AGNPS, and PESTFADE, HSPF, SWAT.

Among complex hydrological assessment models, the Soil and Water Assessment Tool (SWAT) with ArcView GIS or ArcGIS interface is a promising model with numerous calibrations and validations (within permissible range for various time steps) tested for many watersheds worldwide [15]. Shepherd et al. evaluated 14 models and found SWAT to be the most suitable for estimating phosphorus loss from a lowland watershed in the UK. The SWAT divides given watershed into sub-watersheds and further to Hydrologic Response Units (HRUs, unique combination of land use and soil, or slope) within the sub-watershed [16]. SWAT is used for estimating water balances with associated sediment and pollutant from HRUs and flow routed through the channel network of the watershed. In the previously research papers by Cotter et al. [17] and Tripathi et al. [18], SWAT was applied in monthly basis for total flow simulation. The coefficient of determination (R^2) and Nash and Sutcliffe Efficiency (E_{NS}) values were of 0.76 and 0.77 for calibration in Cotter's study[17], and 0.98 and 0.97 for Tripathi's calibration in their studies[18]. However, SWAT simulation on high temporal resolution (with sub-daily time step, sub-hourly time steps) is not widely used despite its availability in SWAT model on this time resolution with combination of sub-daily rainfall data and Green — Ampt infiltration method [19,20]. In Diluzio et al. study [21], the SWAT was used to simulate hourly stream flow prediction with the input data of gridded precipitation (NEXRAD) and then compared results for 24 events with measured flow, giving promising $E_{NS} > 0.79$, except a couple of events. In case of unavailability of precipitation data at required temporal resolution, ESWAT (Enhance soil and water assessment tool) model, developed by Debele et al. [22], successfully disaggregate daily rainfall data (along with other climatic parameters) into hourly data sets for simulation of hydrological and water quality with sub-daily time steps with R^2 and E_{NS} values of 0.6 and 0.65, respectively.

The SWAT sub-daily simulation using measured hourly rainfall data set, considering rainfall intensity, is assumed to be real response of the watershed in generating runoff and sediment at the instant time than SWAT simulation with daily time setup. Thus, predicted runoff is assumed to be precise information to the watershed planners and decision makers, implementing project of flood mitigation and other management practice for maintaining a healthy watershed in sustainable manner. The hourly simulation in previous studies was applied for bigger watersheds with disaggregated or gridded precipitation, not for field scale watersheds with measured sub-daily rainfall data. Simulated flow at bigger watershed outlet with SWAT hourly simulation could match measured flow data reasonably well without validation of flow from fields within the watershed because of complex watershed behaviors to rainfall-runoff processes. Hence, with proper validation of SWAT predicted runoff from field-sized watershed with SWAT sub-daily run, the accuracy for bigger watershed can be secured.

Therefore, the objective of this study was to set up SWAT sub-daily simulation using measured sub–daily rainfall data modifying SWAT configuration along with calibration and validation for hydrology component using measured flow data and measured sub-daily rainfall data at the watershed under study.

2 Methodology

2.1 Study area

The study area, Jawoon-ri watershed (Fig. 1), falls in the northern part of the South Korea and situated at 37° 52′ N and 127° 43′ E. The area of the watershed is about 0.8 ha with the elevation ranging from 650 to 700 m MSL (mean sea level). Runoff generated at the study area was transported to the main outlet through concrete channels network constructed at the edge of the field. Its hourly flow variation was monitored with precipitation from the experimental setup at main outlet of sediment settling point (Fig. 1). Measured precipitation data and runoff were used for calibration and validation of the SWAT sub-daily flow prediction.

2.2 General rainfall and temperature at the watershed

General rainfall and temperature data are described to provide a brief idea of rainfall and temperature patterns in the study area. Monthly variations in precipitation and average maximum air temperature for the year 2007 and 2008 in the study area are portrayed in Figs. 2(a) and 2(b). The highest amount of precipitation was above 400 mm received in the month of August, 2007 and June, 2008. Average annual precipitation is 1163 mm, of which more than 75% occurs during summer (June to September). The average maximum temperature is 30°C in the month of August and average minimum is below 5°C in the month of January.

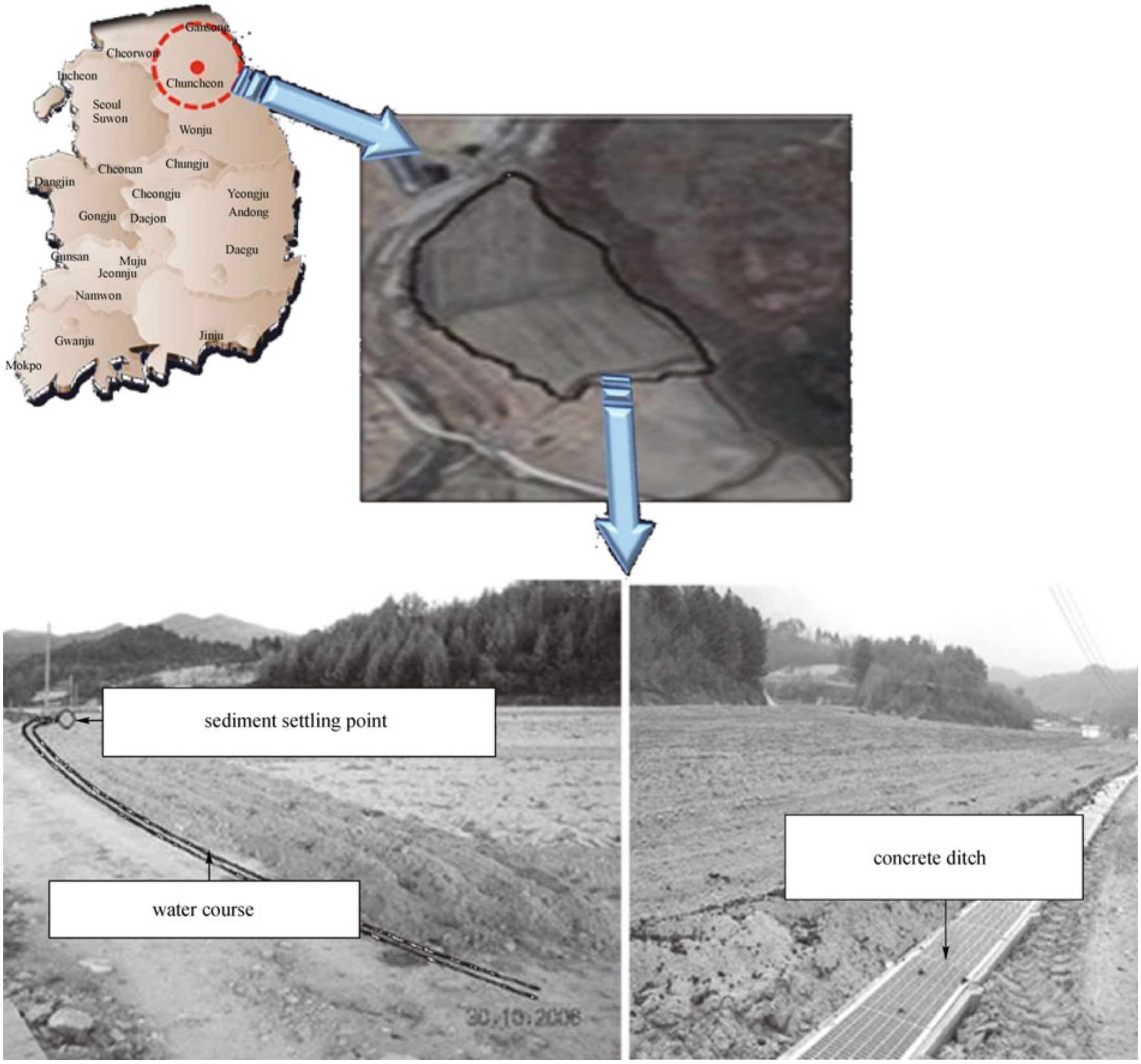

Fig. 1 Location of study area with drain channel

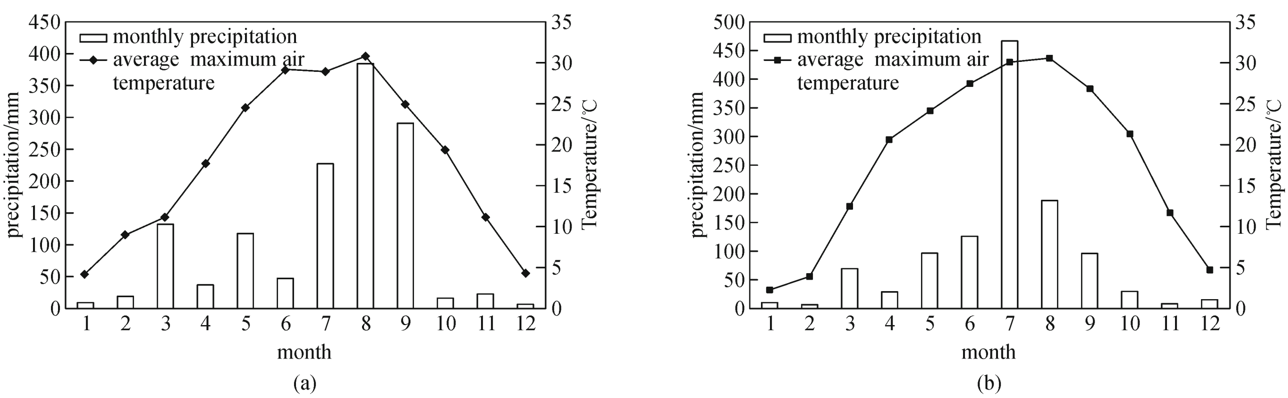

Fig. 2 Temperature and precipitation for 2007(a) and 2008(b)

2.3 Modification of digital elevation model (DEM)

The DEM in SWAT is crucial to divide watershed into several sub-watersheds (sub-basin) for simulation of hydrology and water quality through the channel networks within the watershed. Thus spatial resolution of DEM is important in defining channel networks and sub-watershed boundaries. However, only contours of 5 m is available for the study area, which is not detail enough to route flow generated at each field (sub-basin) to the desired outlet (main outlet) of the study area. In this study, AVSWT 2005 [23] was used to delineate sub-watershed boundaries. With 5 m DEM, it was not possible to delineate sub-watershed boundaries as expected. Thus, sub-watershed boundaries were delineated with visual inspection of overland flow paths in the real field after linear interpolation of the 5 m DEM to finer cell size DEM. However, sub divisions of watershed with automatic delineation did not mask the whole watershed as shown in Fig. 3(a). Thus, manual delineation of sub-watersheds was performed to reflect the study area at the field (Fig. 3(b)).

The SWAT model estimates field slope length in each sub-basin based on the relationship between average slope and average field slope length [24,25]. Average slope values of HRUs were exaggerated with coarse DEM resolution. Thus, measured field slopes and slope lengths were used for each HRU in each sub-basin at the study area. The field slope lengths of 59.5, 70.0, 79.7, 64.4, 50.8 m were used for HRUs in combination with an average slope of 5.5%, for all with some modifications.

2.4 Land uses, soil, and weather data at the study watershed

The study area consists of agricultural fields with silt loam (21.00% clay, 52.74%s silt and 26.26% sand) classified as AnB type. As a common practice in Korea, the field was reconditioned with a layer of 250 mm soil for suitable agricultural production. The farmers recondition their agricultural fields every 2–3 years to compensate soil loss and to provide enough root zone for cash-crops. However, due to heavy cultural operation over the years, saturated conductivity for first two soil layers defined in SWAT has lowered than default values (as set by attribute of soil map) as shown in the study by Heo et al. [26]. With these modifications, the SWAT simulated flow matches the measured flow data well. Table 1 shows soil properties that resemble the real field data.

The remaining climatic data required to run SWAT was obtained from the nearest weather station. Sub-daily precipitation data was calculated using Green and Ampt infiltration method for hourly runoff simulation in the study area. The SWAT is capable to locate start date in the data file thereby save time on the user's part. Unlike daily precipitation data, SWAT verifies that the date is correct on all lines. The number of lines of precipitation data per day is determined by the minute that was assigned to IDT variable in file.cio and was set 60 for hourly rainfall data. Sequential lines are assigned to each hour of a rainy day with their corresponding precipitation datum recorded. For non-rainy days, only one line is required without further lines for every hour in the day indicating year, Julian day and hours with blank delimiter. Table 2 shows the file

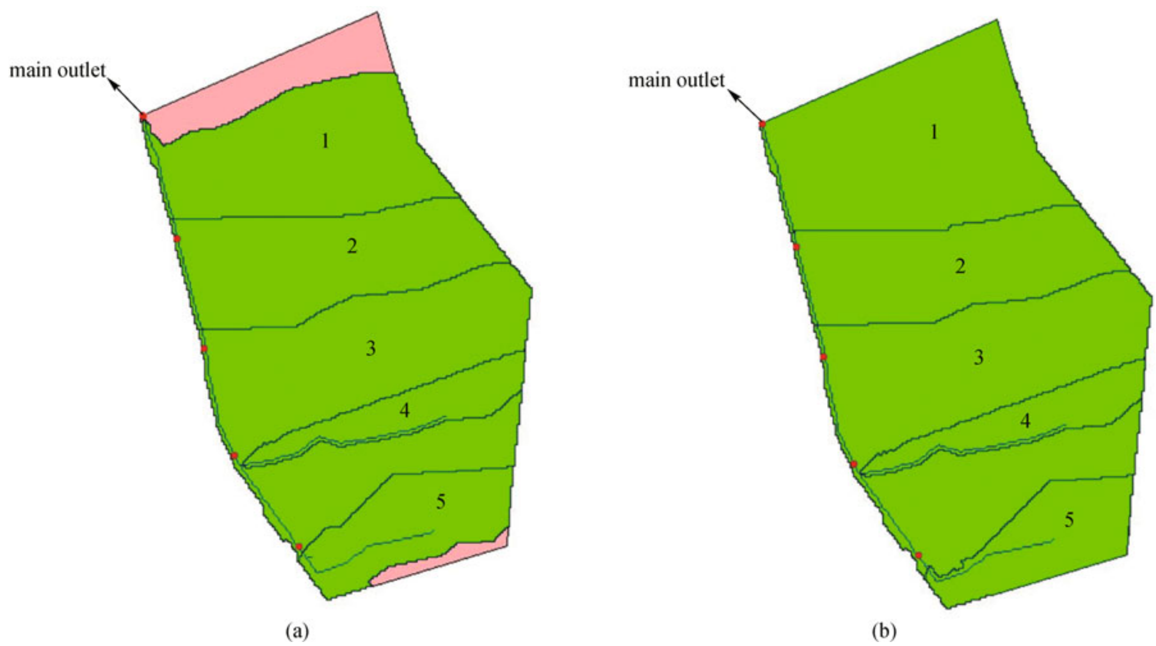

Fig. 3 Sub-watershed boundaries with manual delineation after automatic delineation. (a) automatic delineation; (b) manual delineation

Table 1 Soil properties at different soil horizon at the watershed

soil class/AnB	five soil layers from surface				
	Z1	Z2	Z3	Z4	Z5
depth/mm	250	453.2	631	1215.2	1901
bulk density moist/$(g\cdot mL^{-1})$	1.4	10.25	1.35	1.85	1.8
saturated hydraulic conductivity Ksat./ $(mm\cdot h^{-1})$	20	10	20	20	20
organic carbon/(wt. %)	2.91	0.97	0.97	0.32	0.11
clay/(wt. %)	21	14	14	20	20
silt/(wt. %)	52.74	55.62	55.62	7.83	37.83
sand/(wt. %)	26.26	30.38	30.38	42.17	42.17

Table 2 Precipitation data format in SWAT sub-daily run

year	Julian days	hour	PCP/mm
2008	170	0:00	0.0
2008	170	1:00	0.0
2008	170	2:00	0.0
2008	170	3:00	0.5
2008	170	4:00	2.0
2008	170	5:00	4.0
2008	170	6:00	3.5
2008	170	7:00	3.5
2008	170	8:00	2.5
2008	170	9:00	2.5
2008	170	10:00	3.5
2008	170	11:00	3.5
2008	170	12:00	1.0
2008	170	13:00	17.0
2008	170	14:00	0.0
2008	170	15:00	0.0
2008	170	16:00	0.0
2008	170	17:00	0.0
2008	170	18:00	0.0
2008	170	19:00	0.0
2008	170	20:00	0.0
2008	170	21:00	0.0
2008	170	22:00	0.0
2008	170	23:00	0.0

format for sub-daily precipitation in a rainy day. Other climatic data files required for SWAT sub-daily were not changed in daily SWAT run data sets.

2.5 Analysis of hourly precipitation

Variations in precipitation during different events for the year 2007 and 2008 are shown in following Figs. 4(a) and 4(b). The events in 2007 are greater than those in 2008. In recent years, the rainfall pattern changes due to climate changes. The highest precipitation recorded on the 221st day at 15:00 h in 2007 is about 112 mm. The amount of precipitation observed at 13:00, 4:00 and 16:00 h on 220th, 258th and 216th days are 36, 33.5 and 32.5 mm, respectively. The precipitation on the storm event days of 221st, 220th, 247–258th and 216–217th are about 136.5, 71, 92 and 92.3 mm, respectively. The scenario for the year 2008 can be described similarly. The amount of total rainfall that produced runoff was 1474.8 mm during the year 2007, whereas 1140.4 mm during 2008. The crucial analysis of the hourly precipitation data set is important for precise runoff prediction in the SWAT sub-daily runs.

2.6 Modification in SWAT input files for sub-daily simulation

The SWAT model provides numerous options for prediction of different watershed management practices. The hourly simulation of SWAT in existing shape is not a widely used option among many researchers but it can be a good tool if manual modification in SWAT input files is made. The file.*cio*, *.*bsn*, *fig.fig* and *pcp.pcp* are the files that need some modification to their variable in supporting SWAT sub-daily simulation option. The *file.cio* contains the information related to variable for modeling option and climatic input according to the number assigned to the respective variables for the calculation of climatic parameters and others. Basin input file in the SWAT model refers to heterogeneous characteristic of watershed through different variables. The variables IDT and IEVENT in *file.cio* and *.BSN should be 60 and 3, respectively, for rainfall data file recorded for every 60 min and simulation of runoff using the Green and Ampt infiltration method. The 'Savecon' command was added to the existing *fig.fig* file to obtain the hourly simulated result in a separate file. The next important thing for sub-daily run is *pcp.pcp* file, which should be in sub-daily format as shown in Table 2. This is a prerequisite according to the modifications made in *.cio*, *.*bsn* and *fig.fig* files. In addition to these modifications, the options that were

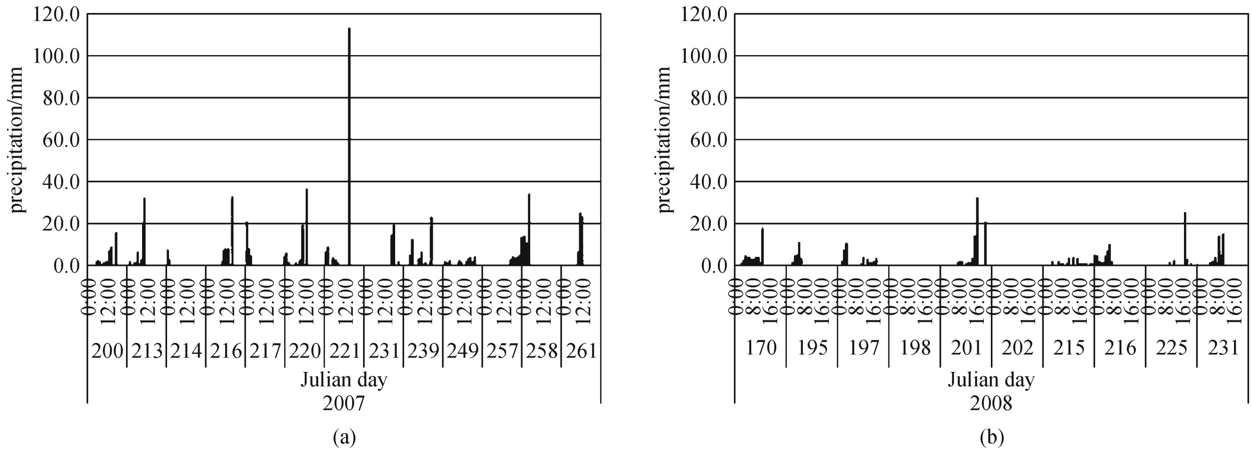

Fig. 4 Hourly precipitation variation for events of 2007(a) and 2008(b) at the study watershed

used in this simulation were Preistley-Taylor for Potential Evapotranspiration (PET) and Variable Storage routing method for hourly stream routing. More detailed information for sub-daily run can be found in '*input.std*' file.

2.7 Calibration and validation of estimated flow

Calibration and validation of the model are important aspects prior to its application to real world problem. These processes were conducted for reasonable prediction that co-relates the measured value to greater extent. Calibration of a hydrologic component was carried out in accordance with the SWAT user manual and other published literature by SWAT users ([27–29]). The most sensitive factors in hydrologic component that had been selected for calibration and validation processes were CN2 (curve number), LAT_TTIME (lateral flow travel time), ESCO (soil evaporation compensation factor), GWQMN (a threshold minimum depth of water in the shallow aquifer required for return flow to occur), GW_DELAY (ground water delay time), ALPHA_BF (base flow alpha factor) and REVAPMIN (minimum depth of water in shallow aquifer for re-evaporation to occur). R^2 and E_{NS} were used to evaluate SWAT sub-daily performance. The SWAT sub-daily was calibrated with measured sub-daily precipitation data and flow data in the year 2007 and 2008. Total events of 18 events (10 events from 2007 and 8 events from 2008) were considered (9 events for calibration and another 9 events for validation). The hourly simulated values corresponding to considered events were averaged from hourly result to the events due to unavailability of measured hourly flow data from the study watershed for evaluation of SWAT sub-daily simulation. The SWAT daily simulation was also performed in the study with the same input parameter set, which were used in SWAT sub-daily calibration and validation. Comparison of estimated flow using SWAT sub-daily and daily simulations were made to explore impacts of sub-daily precipitation on flow estimation although we can expect different simulated results when calibrating the SWAT with daily option.

3 Results and discussion

3.1 SWAT hourly simulation

After modification in the input files and sub-daily data, the hourly simulation was done for the study watershed. Hourly-based flow results are summarized for rainfall event days of 2007 and 2008. The summary results are tabulated as shown in Table 3. In calibration process, the simulated flow values were compared with the measured values by adjusting values of the sensitive parameters (CN2, LAT_TTIME, ESCO, GWQMN, GW_DELAY, ALPHA_BF, REVAPMN). The corresponding values adjusted for the these sensitive parameters during calibration were 80, 0.5 d, 0.98, 50 mm, 10 d, 1.048 and 1 mm, respectively. Also, sensitivity of the SWAT model to various hydrological parameters was analyzed using SWAT models under the same condition of delineated watershed and HRUs. The sensitivity ranking for the parameters is shown in the following Table 4 and the sensitivity analysis of CN2, ESCO, GW_DELAY, ALPHA_BF, GWQMN, REVAPMN, LAT_TIME was performed. The plastic mulching and tractor compaction in the study area was significantly observed which cause CN2 with the highest sensitivity ranking than other ground water hydrological parameters.

The corresponding sensitive parameters values were both increased and decreased by 10% to evaluate its impact on flow estimation. When the sensitive parameters were increased by 10% (Table 5), the simulated flow

Table 3 Hourly flow results in calibration and validation for each storm events

years	measured precipitation /mm	Julian days (Events)	hourly simulation cubic meter per sec/(CMS)	measured cubic meter per sec/(CMS)	remarks
2007	41.5	200	3.46E-04	1.50E-04	calibrated events
	73	213–214	1.84E-03	1.90E-03	
	92.3	216–217	1.80E-03	1.94E-03	
	71	220	2.44E-03	1.63E-03	
	136.5	221	5.65E-03	6.90E-03	
	35.5	231	1.11E-03	6.02E-04	
	52	239	1.21E-03	1.77E-03	
	25	249	6.53E-04	4.32E-04	
	92	257–258	1.56E-03	3.07E-03	
	53	261	1.88E-03	2.03E-03	
2008	41.5	170	5.16E-05	2.43E-04	validated events
	23	195	1.10E-05	1.62E-04	
	29	197–198	1.88E-05	3.47E-04	
	75	201–202	1.25E-03	1.02E-03	
	24	215	4.73E-05	1.85E-04	
	27	216	2.80E-04	6.71E-04	
	31	225	3.02E-04	3.70E-04	
	39.5	231	9.60E-04	7.75E-04	

Table 4 Parameter range of variables derived from sensitivity analysis

parameter	description	range	rank	mean	maximum	variance
ALPHA_BF	base flow alpha factor	0.00 to 2	4	3.51E-03	3.51E-02	3.51E-03
CN2	curve number	−25 to 90	1	6.25E-02	0.20441	6.25E-02
ESCO	soil evaporation compensation factor	0.00 to 1.00	2	1.70E-02	5.62E-02	1.70E-02
GW_DELAY	ground water delay time	−10 to 10	3	1.21E-02	3.07E-02	1.21E-02
GWQMN	a threshold minimum depth of water in the shallow evaporation coefficient	0.00 to 1000	5	0.00E + 00	0.00E + 00	0.00E + 00
REVAPMN	minimum depth of water in shallow aquifer for re-evaporation to occur	−100 to 100	5	0.00E + 00	0.00E + 00	0.00E + 00
LAT_TIME	lateral flow travel time	0.000 to 50.00	5	0.00E + 00	0.00E + 00	0.00E + 00

Table 5 Corresponding parameters values at 10% lower and higher

parameters	values of parameters fixed at calibration and validation	10% higher	10% lower
CN2	80	88	72
ESCO	0.98	1.078	0.882
GW_DELAY	10	11	9
ALPHA_BF	1.048	1.1528	0.9432
GWQMN	50	55	45
REVAPMN	1	1.1	0.9
LAT_TIME	0.5	0.55	0.45

Table 6 Outflow response at 10% change in sensitive parameters

measured (CMS)	flow values at fixed parameters hourly	out flow at 10% higher parameters from fixed	out flow at 10% lower parameters from fixed	change in flow by 10% higher parameters values	change in flow by 10% lower parameters values
1.50E-04	3.46E-04	4.28E-04	2.33E-04	2.36E + 01	3.28E + 01
1.90E-03	1.84E-03	0.001895	1.69E-03	2.99E + 00	8.26087
1.94E-03	1.80E-03	0.001901	0.001723	5.61E + 00	4.277778
1.63E-03	2.44E-03	5.75E-03	2.38E-03	1.36E + 02	2.30E + 00
6.90E-03	5.65E-03	6.02E-03	5.46E-03	6.58E + 00	3.39823
6.02E-04	1.11E-03	1.04E-03	1.14E-03	−6.13E + 00	−2.43E + 00
1.77E-03	1.21E-03	1.30E-03	1.04E-03	7.52E + 00	13.96694
4.32E-04	6.53E-04	5.97E-04	6.40E-04	−8.58E + 00	2.01E + 00
3.07E-03	1.56E-03	0.001692	0.001122	8.43E + 00	28.0641
2.03E-03	1.88E-03	1.95E-03	1.72E-03	3.67E + 00	8.56383
2.43E-04	5.16E-05	2.34E-04	3.93E-05	3.53E + 02	2.38E + 01
1.62E-04	1.10E-05	5.79E-06	5.74E-06	−4.74E + 01	47.81818
3.47E-04	1.88E-05	0.000157	1.36E-05	7.36E + 02	27.71809
1.02E-03	1.25E-03	0.001513	0.000502	2.11E + 01	59.828
1.85E-04	4.73E-05	4.45E-05	2.91E-05	−5.96E + 00	38.52008
6.71E-04	2.80E-04	4.24E-04	1.76E-04	5.16E + 01	37.17857
3.70E-04	3.02E-04	2.72E-04	1.55E-04	−9.80E + 00	48.74172
7.75E-04	9.60E-04	8.69E-04	6.46E-04	−9.50E + 00	32.67708
			total % change	70.5	23.2

increased by 70.5%, while when decreased by 10% (Table 5) the simulated flow decreased by 23.20%. When the parameters were deviated from fixed values by 10%, the parameters were observed to be more sensitive toward by increasing than lowering the parameter values. Table 6 below shows respective outflow at deviated values of 10% in the considered parameters.

Figure 5(a) shows flow results during calibration of SWAT sub-daily for the first 9 rainfall events. Overall trend extent of matching simulated flow values with measured during calibration are shown in Fig. 5(b) with the R^2 = 0.88 and E_{NS} = 0.88. Rainfall amount and antecedent moisture condition during simulation affect estimated flow data. Hourly simulation results for remaining 9 events during validation (2007–2008) are shown in Fig. 6(a) and Fig. 6(b). The R^2 and E_{NS} value for validation are observed to be 0.91 and 0.84. To evaluate the effect of precipitation (measured at interval of 15 min, 1 h, 2 h, 6 h and 12 h) on simulated results, flow out from the study watershed was compared with measured data. The respective R^2 and E_{NS} at these times resolutions are shown in Table 7. R^2 and E_{NS} decreases with the increase of time interval considered in measuring precipitation data which depicts that the simulated flow out due to precipitation data recorded at lower interval is better in swat sub-daily configuration. With the acceptable values of R^2 and E_{NS} for both calibration and validation in SWAT sub-daily simulation (hourly) for runoff estimation, the SWAT model with sub-daily configuration can be applicable for further scenario analysis at different condition of management practice.

3.2 SWAT daily simulation

The SWAT sub-daily calibration and validation provides higher R^2 and E_{NS} values, indicating the SWAT sub-daily should be used for exact simulation of runoff generation from field sized watershed. In this study, SWAT daily simulation results were also compared with measured flow data collected at the study area (Figs. 7(a) and 7(b)).

The daily simulation over-estimates for all the events considered during 2007–2008 except for only one event 257–258 is under estimated. The maximum flows during these events occurred in 2007 on the Julian day of 201 and followed by events on Julian day of 220, 216–217 in the same year. In daily SWAT application, the precipitation for corresponding Julian day were summed up daily from the hourly precipitation data which contribute to occur greater amount of flow than measured using SCS CN method in SWAT. The trend and extend of simulated values with measured for flow were found to be R^2 (0.79) and E_{NS} (−0.01) as shown in Fig. 7(b). The SWAT sub-daily run uses hourly time step precipitation and Green and Ampt infiltration for runoff calculation. The sub-daily SWAT has

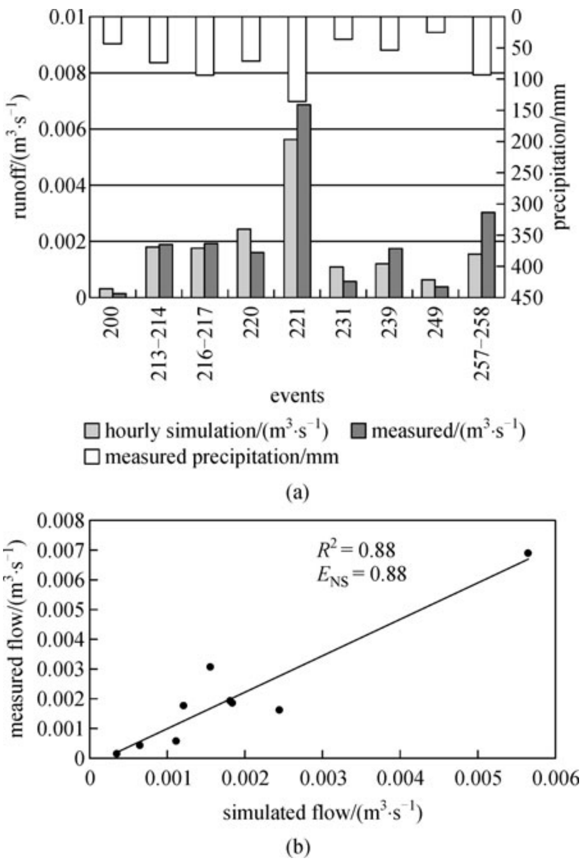

Fig. 5 Comparison of simulated and measured runoff for calibration: (a) simulated and measured runoff in calibration; (b) comparison of simulated and measured runoff for calibrated events

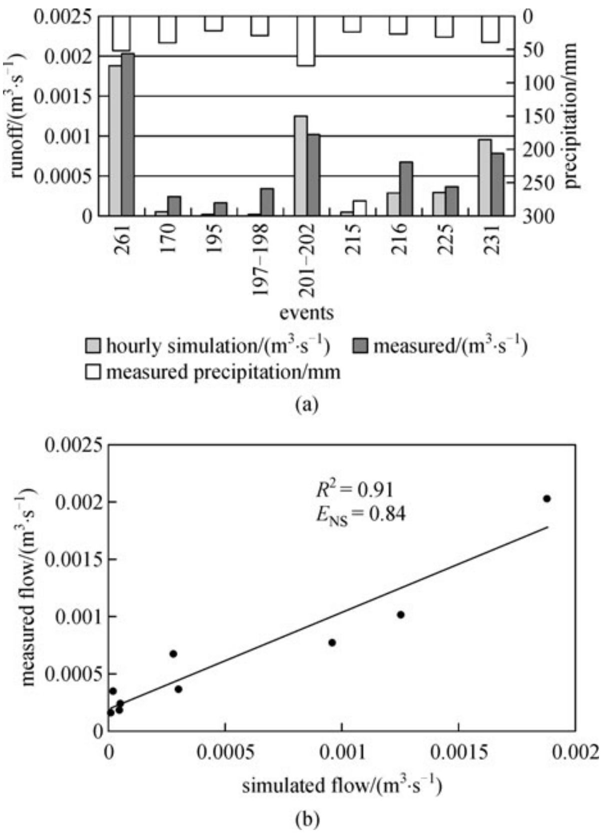

Fig. 6 Comparison of simulated and measured runoff for validation: (a) simulated and measured runoff in validation; (b) comparison of simulated and measured runoff for validated events

Table 7 Simulation result at different time resolution of precipitation records

time resolution of precipitation	15 minute	hourly	2 hourly	6 hourly	12 hourly
E_{NS}	0.804	0.874	0.853	0.83	0.462
R^2	0.817	0.898	0.875	0.855	0.6620

shown greater accuracy in prediction of runoff closely with higher R^2 and E_{NS} values than SWAT daily simulation considering cumulative rainfall during each hours of the day with SWAT SCS CN method. Hence, with the higher values of R^2 and E_{NS} in SWAT sub-daily simulation in the study, it is realistic to use Green and Ampt option for runoff prediction.

4 Conclusions

In many watersheds, total flow at the watershed outlet is assumed to be the crucial hydrological component which is a driving force of sediment load and other nonpoint source pollution simulation from the watershed. The exact quantification of the flow in combination of sediment and pollutant has always been rationale behind development and application of various hydrologic and water quality model.

In this study, SWAT sub-daily was evaluated for hourly runoff prediction at field-sized study watershed. The evaluation index R^2 and E_{NS} values for predicted runoff from SWAT sub-daily were within acceptable range > 0.80 during calibration and validation in the study. The sensitivity analysis focusing on the hydrological parameters were ranked in sub-daily SWAT configuration wherein CN2 was observed with the highest sensitivity followed by ESCO, GW_DELAY, ALPHA_BF, GWQMN, REVAPMN, LAT_TIME reflecting the field management system of plastic mulching and tractor compaction during cultural operation in the study area. However the model sensitivity was further evaluated in the response of flow from the study area at 10% change (higher and lower) in sensitivity parameters, resulting in 70.5% higher and 23.20% lower in simulated outflow.

The study also comparatively evaluates its results with SWAT daily results for performance evaluation of the

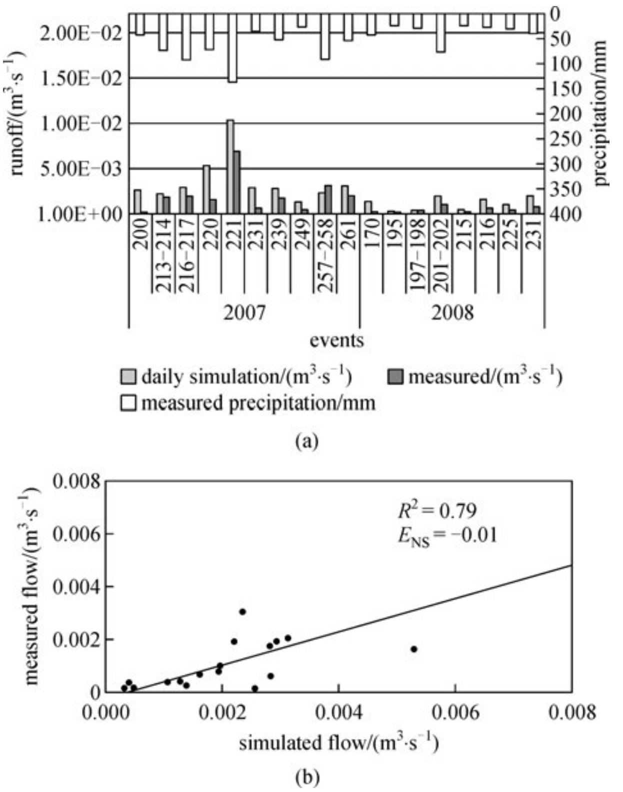

Fig. 7 Comparison of daily simulated and measured runoff for Eevents of 2007 and 2008 : (a) daily simulated and measured runoff for events of 2007 and 2008; (b) comparison of daily simulated and measured runoff at similar condition of SWAT sub-daily

SWAT sub-daily, which showed better performance than the daily simulation. The effect of precipitation at different temporal resolution in simulation of flow showed significantly higher values of E_{NS} and R^2 for hourly precipitation than other time resolution (2 h, 6 h and 12 h time resolution) of precipitation. Hence it was found that the SWAT sub-daily with Green-Ampt infiltration method was proven to be efficient for runoff estimation at field sized watershed with higher accuracies and the results can be efficiently used to develop site-specific Best Management Practices (BMPs) considering rainfall intensity, rather than simply daily rainfall data. With the result of the study, it is advisable to use SWAT sub-daily simulation for critical analysis of field scale watershed in runoff estimation. The SWAT sub-daily with higher accuracies in flow estimation could be used to evaluate the various BMPs, such as Vegetated Filter Strip (VFS) using sub-daily time step VFSMOD modeling system because the SWAT VFS module uses very simple regression equation to evaluate the VFS.

Although promising result was obtained from SWAT sub-daily flow estimation, more in-depth researches are needed for accurate simulation of sediment and nonpoint pollutant loading estimation using SWAT sub-daily.

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