SWAT Hydrological Model for Watershed Management in Watrak River Basin

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Abstract:-

Worldwide development and population increase over the years have led to stress on water resources and degradation of watershed in general. This has affected lives of many people negatively, especially those belonging to weaker sections of the society and living downstream in particular. Fortunately, technology has also provided ways to mitigate the negative externalities of development.

SWAT Hydrological modeling is one such answer to check and enhance the watershed development with positive externalities. The northern part of Gujarat is one such area, which has not benefitted from development of Narmada Command area. Further, a sizable population in this region belongs to weaker section of the society. Hence, application of the SWAT Hydrological modeling to the Watrak river watershed region is a fit case for ensuring development with equity in otherwise developed western state of Gujarat, India. Further, with the availability of required data from various sources including State Water Data Centre has relatively reduced the task of building a reasonable acceptable model.

Keywords: GIS Technology, SWAT hydrological modeling, SWAT CUP, Watershed Management

I. STUDY AREA DESCRIPTION AND INPUT DATA

Water, worldwide is fast becoming a scarce resource due to increase in world population, industrialization, urbanization and uncertain rainfall. India though being blessed with immense water resources is of late facing water stress in several parts of the country. The western most state of India, Gujarat falls into semi arid region except for few parts of southern Gujarat. Fortunately for most parts of Gujarat, development of a wide spread canal network starting from Narmada river has shielded it from water stress. This is one of the finest examples of watershed development and its extension.

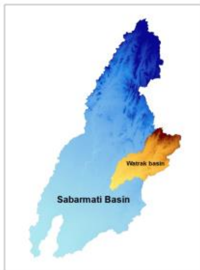
However, not all parts of Gujarat are blessed with narmada waters and hence need watershed development for their prosperity. One such part is Northern Gujarat. Bordering Rajasthan and Madhya Pradesh, this region is relatively less developed. Hence, the study for watershed development through SWAT Hydrological modelling was carried out over one of the rivers namely Watrak flowing through this region.

The research work was undertaken on Watrak river basin, a part of Sabarmati river basin in Gujarat, the western state of India. The Watrak river originates in Panchara hills, a part of Aravali hills, in Dungarpur district of Rajasthan and after travelling for a distance of 248 kms in south west direction meets the river Sabarmati on its left bank. It covers the remaining drainage area of the main river downstream of the confluence of Khari and upto its meeting with the Gulf of Khambhat. Watrak and its tributaries drain an area of 8638 km^2. The mean annual surface water resource in tl ^{3}.

WATRAK BASIN

Sabarmati river is one of the major west flowing river of India. and after travelling 371 kms meets Gulf of Khambhat in the Arabian sea (48 kms in Rajasthan and 323 kms in Gujarat). Sabarmati basin extends over the states of Rajasthan and Gujarat having an area of 21,674 km^2. The basin is roughly triangular in shape with the Sabarmati river as the base and the source of Watrak river as the apex point.

SABARMATI BASIN



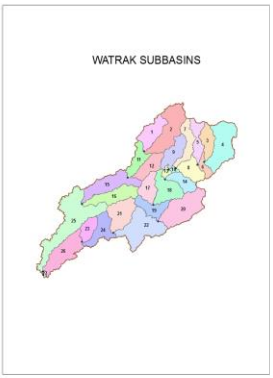
SABARMATI AND WATRAK BASINS

The elevation of the Watrak river basin varies from 47 m to 378 m, with mean elevation being 175 m. 94% of area of the basin was having terrain slope of 10% or less. Agriculture comprised of 73% of land use followed by 23 % of land use under pasture. 2472.6 km^2 of watershed area drains into the outlet where the rain gage station Ambaliyara is situated. Vertisols form the dominant soil group with a coverage of 56 % of basin area.

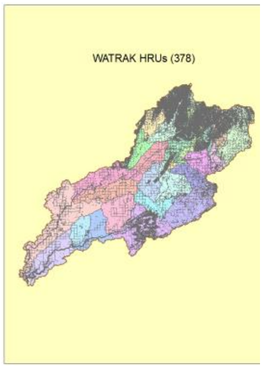
Luvisols cover about 34 % of basin area [FAO UNESCO soil map of the world]. Daily weather data for precipitation, maximum and minimum temperature and other related meterological data like were obtained from the rain guage station of ambaliyara for a period of 1999 to 2014. Daily stream flow was also obtained from Ambaliyara rain guage station.

Data layers include 30 m resolution DEM, FAO soil raster of the region, land use shape file of the region were obtained from swat database. (https://swat.tamu.edu/data/india-dataset/)

The Watrak river basin is divided into 27 subbasins with the help of Geographical Information system (GIS) and using a DEM and stream network. Each subbasin is further subdivided into 378 HRUs, which are determined by unique interaction of land use, soils and slope within each sub-basin.



WATRAK SUBBASINS



WATRAK HRUs

II. MODEL DESCRIPTION

SWAT (Soil and Water Assessment Tool) developed by USDA is a physically based distributed model which helps in predicting and simulating the land phase of hydrologic cycle as well as the impact of land management practices on water, sediments in watersheds in daily time steps[1,2,3]. Simplying further, SWAT model is designed to simulate the water and sediment movement from individual watersheds through the river systems[4]. SWAT model is flexible enough to include tanks, reservoirs, check dams offstream as well as onstream in simulating the land phase[1].SWAT simulates 8 important components viz hydrology, erosion, sediment transport, weather, nutrients, crop growth, pesticides, agricultural management and soil temperature[5].Major hydrological processes simulated by the model are infiltration, surface runoff, channel routing, shallow aquifer, deep aquifer, percolation and evapotranspiration[5]. The major advantage of SWAT model is that unlike conventional simulation models, it needs little calibration to run and hence can be used on unguaged watersheds also[6].

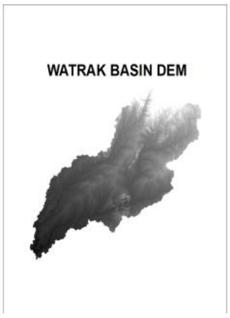
Model outputs incorporate water-balance components (like surface run-off, recharge, percolation, lateral flow, evapotranspiration, sediment yield) at the scale of each sub-watershed and at daily, monthly or annual time steps[1].

Each watershed is first divided into sub-basin and then into hydrologic response units (HRUs) based on the land use, soil distribution and slope. The water storage components are soil profile, shallow aquifer, deep aquifer and snow cover. A daily water budget is estabilished for each HRU based on precipitation, surface runoff, evapotranspiration, base flow, percolation and soil moisture change. Each HRU for each sub-basin/watershed computes runoff using Soil Conservation Services developed Curve Number (CN) procedure. It is a function of soil permeability, landuse and soil water conditions[2].

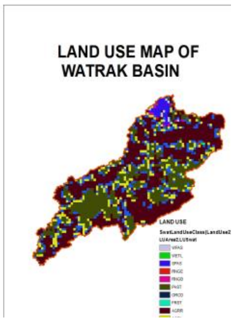
Spatial datasets used in the study included DEM, soil, landuse and land cover, daily weather, daily discharge.

III. METHODOLOGY

SWAT Hydrological model building required certain spatial and non spatial datasets. Spatial datasets used in the study included Digital Elevation Model (DEM), Landuse raster, soil map shapefile. These India specific datasets were obtained from SWAT website[https://swat.tamu.edu/data/india-dataset/]. The data was preprocessed and clipped as per the Watrak river basin and projected in UTM43N Projection which is appropriate for the study area. The weather data for the study area was obtained from SWAT website and also from State Water Data Centre, Gandhinagar. The State Water Data Centre data included the discharge data of guage stations located in the study region and for the period ranging from 1991 to 2014.



WATRAK BASIN DEM



WATRAK BASIN LAND USE MAP

WATRAK BASIN SOIL MAP

SWAT2012 model was run for a period of 16 years from 1999 to 2014 for the basin. Initial 3 years was chosen as warm up period for the model. First time the model was run with the actual land use data as obtained from SWAT land use data base for the region. The model was calibrated and validated using SWAT CUP SUFI2. The model was calibrated for the period from 2006 to 2009. Validation was carried out for the period from 2010 to 2012. Sensitivity analysis, Calibration and Validation was done using sufi2 module of SWAT CUP. Discharge data obtained from Ambaliyara guage station was used for this purpose. Satisfactory results for calibration and validation of the model were obtained which shall be discussed in the section below.

IV. RESULTS AND DISCUSSIONS

A. Parameter Sensitivity

In order to reduce the time of calibration, sensitivity analysis is essential. Sensitivity analysis helps in identifying sensitive parameters[7,8,9]. Following 13 parameters along with their minimum, maximum and fitted values as mentioned in the table below were found appropriate for model calibration in SWAT CUP for WATRAK basin conditions after several iterations and sensitivity considerations[8].

Table-I: SWAT Parameters with their range and fitted values.

Sr. No.	Parameter_Name	Fitted_Value	Min_value	Max_value
1	CN2.mgt	-34.873028	-41.560604	4.560603
2	ALPHA_BF.gw	0.696108	0.310801	1.089199
3	GW_DELAY.gw	-52.941105	-389.555481	206.222153
4	GWQMN.gw	0.107224	-0.571104	1.23777
5	DEEPST.gw	34897.51953	30566.28516	44767.05078
6	REVAPMN.gw	377.468323	165.907486	554.092529
7	RCHRG_DP.gw	0.739957	0.366723	0.793276
8	CANMX.hru	1.057603	1.006248	1.360418
9	SURLAG.bsn	-6.599984	-9.860242	-1.606424
10	SOL_BD(..).sol	0.070041	-0.48436	0.291026
11	SOL_AWC(..).sol	0.051497	-0.010826	0.450826
12	SOL_ALB(..).sol	0.507453	-19.121674	9.121675
13	SOL_K(..).sol	-1.701133	-2.264353	-0.055647

Sensitivity of various parameters is as shown in the table below. The parameters are listed in decreasing order of sensitivity as per their P-value. The Parameter values were calibrated as per their sensitivity for obtaining optimum results.

Table-II: Global Sensitivity

Parameter Name	t-Stat	P-Value
1:R__CN2.mgt	-5.146516310	0.000001655
3:V__GW_DELAY.gw	-2.539333787	0.012904974
4:V__GWQMN.gw	-1.901345209	0.060605468
7:R__RCHRG_DP.gw	-1.101689891	0.273670286
11:R__SOL_AWC(..).sol	0.711517038	0.478689461
13:R__SOL_K(..).sol	-0.689877097	0.492128936
6:R__REVAPMN.gw	0.484428939	0.629312962
8:R__CANMX.hru	-0.385474928	0.700837401
5:R__DEEPST.gw	0.309407115	0.757760269
12:R__SOL_ALB(..).sol	0.135438533	0.892581669
2:V__ALPHA_BF.gw	0.122417868	0.902853706
9:R__SURLAG.bsn	0.069013692	0.945138936
10:R__SOL_BD(..).sol	0.025051308	0.980072076

B. *Model Calibration and Validation*

Calibration is the process of adjusting the model in such a way that it represents the observed data in a more realistic way[5]. Calibration thus improves model accuracy. Model Validation on the other hand is a process of running the simulation, using a different time series for input data, without changing parameter values used for calibration purpose and replicating the results. Validation can also occur during the same time-period, but for different spatial locations.

During Calibration and Validation, fitness between simulated and observed streamflow data, on an annual basis was determined quantitatively also apart from subjectively. Quantitative measures included two statistics, P-factor and R-factor[10]. P-factor is the percentage of observed data enveloped by our modeling result, 95PPU. R-factor is the thickness of 95PPU envelope. The goal is to capture maximum observations in the 95PPU and at the same time have a small envelope. No hard numbers exists for this two statistics[10]. In the case of WATRAK river basin modeling, P-factor and R-factor for calibration were 0.40 & 4.20; and for validation were 0.27 and 6.20 respectively for discharge at Ambaliyara guage station.

Similarly, other two parameter for quantifying goodness of fit namely, the Determination Coefficient (R^2) and Nash-Sutcliffe model efficiency (NSE) for calibration were 0.09 & 0.02; and for validation were 0.11 and 0.08 respectively.

V. CONCLUSION

The SWAT model was applied for upper Sabarmati basin or more specifically saying on the Watrak river basin. The statistical parameters particularly the NSE and R^2 values for both calibration and validation are in a closer range. Bothe the values are positive, which falls into the zone of minimal accepatibility of the model[4]. Values greater that 0.5 would have been more desirable. Nevertheless, the model is still minimally acceptable and can reasonably predict the effects of varying land management practices/ conservation measures on the water balance components within the basin.

While calibration of model is a tedious task, more work still needs to be done by way of calibrating various parameters so as to get higher quantitative parameters measuring the goodness of fit. This way the predictions made through the model would be further be more conclusive.

VI. REFERENCES

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