Runoff Modelling for Bhima River using Swat Hydrological Model

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***Abstract*--This study, will present a comprehensive modelling environment for SWAT, including automated calibration, and sensitivity and uncertainty analysis. To examine this framework and demonstrate how it works, a study on simulating stream flow in the Bhima River Basin was used, and we compared it with the built-in auto-calibration tool of SWAT in parameter optimization. The results which we get indicate that the method performed well and similarly in searching a set of optimal parameters. Calibration and verification results showed good agreement between simulated and observed data. Model performance was evaluated using several statistical parameters, such as the Nash–Sutcliffe coefficient and the normalized objective function. We got R^2 in Calibration is 0.89 and in Validation is 0.74 and NSE in Calibration and in Validation is 0.81 and 0.77 respectively. The study showed that SWAT model, if properly validated, can be used effectively in testing management scenarios in watersheds. The SWAT model application, supported by GIS technology, proved to be a very flexible and reliable tool for water decision-making.**

Keywords - Calibration and Validation, Sensitive parameters & SWAT model

I. INTRODUCTION

The optimal management of water resources is the necessity of time in the wake of development and growing need of population of India. The National Water Policy of India (2002) recognizes that the development and management of water resources are need to be governed by national perspectives in order to develop and conserve the scarce water resources in an integrated and environmentally sound basis. Prediction of surface runoff is one of the most useful hydrological capabilities of a GIS System. The prediction may be used to assess or predict aspects of flooding, aid in reservoir operation, or be used in the prediction of the transport of water born contamination (Jain, M.K., 1996).

There has been a growing need to study, understand and quantify the impact of major land use changes on hydrologic regime, both water quantity and quality (Engman, E.T., et al, 1991). Hydrological modelling is a powerful technique of hydrologic system investigation for both the research hydrologists and the practicing water resources engineers involved in the planning and development of integrated approach for management of water resources (Schultz, G.A., 1993). Hydrologic models are symbolic or mathematical representation of known or assumed functions expressing the various components of a hydrologic cycle. The susceptibility to the resulting environmental stresses depends on two sets of factors: one, losses in this 'water systems' (such as rainwater runoffs, floods and groundwater contamination) which will eventually determine what fraction of resources are available for human use (where we focus mainly on irrigation and potable water), and two, existing use patterns.

II. STUDY AREA

A. BHIMA BASIN

Bhima River is the major tributary of the Krishna River, flowing through Maharashtra and Karnataka states, western India. It originates near Bhima Shankar Temple in the Bhima Shankar hills in Ambegaon Taluka on the western side of the Western Ghats, known as Sahyadri, in Pune District, Maharashtra state, at 19°04′03″N 73°33′00″E and flows southeastward for 450 miles (725 km) in Maharashtra to join the Krishna in Karnataka.

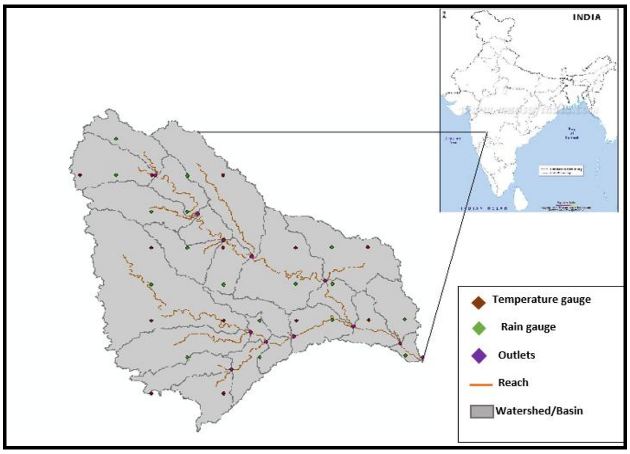

Fig 1- Location Map of the study area

The Bhima basin falls in Deccan plateau and Western Ghats. Around 55% of total basin area lies in the elevation zone of 500-750 m (SRTM; CGIAR, 2006). The Bhima basin has a tropical climate. The average annual rainfall (1969-2004) in the basin is 859 mm. The average annual mean temperature for this period is 26.32°C. The basin falls into four major agro-climatic zones and six agro-ecological zones.

B. Climate

The Bhima basin has a tropical climate. The climate is dominated by the southwest monsoon, which provides most of the precipitation for the basin. High flow in the rivers occurs during the months of August-November and the lean flow season is from Aril to May. Western Ghats exert considerable influence as a climate barrier or rather a divide in the spatial distribution of climate attributes, the temperature, rainfall and relative humidity etc. (WRIS).

C. Rainfall Pattern

According to the India-WRIS database rainfall pattern in the Bhima basin is spatially defined due to favorable geographic location. The climate of the Bhima basin is highly variable, both spatially and temporally. Most of the rainfall falls on the eastern side of the Western Ghats (>3500mm/yr.), while the plains of the Deccan Plateau receive <450mm/yr. The average rainfall over the basin is 746mm/yr. During the three months, March to May, the rainfall in the most parts of the basin varies from 20 mm to about 50 mm June to September are the four months of the south-west monsoon during which all parts of the basin receive their maximum rainfall.

D. Temperature

The western area of the basin being closer to sea, is less continental and presents a comparatively low annual range of temperature. In winter while the maximum temperature in all parts varies between 30°C and 35°C, the minimum shows the significant variations.

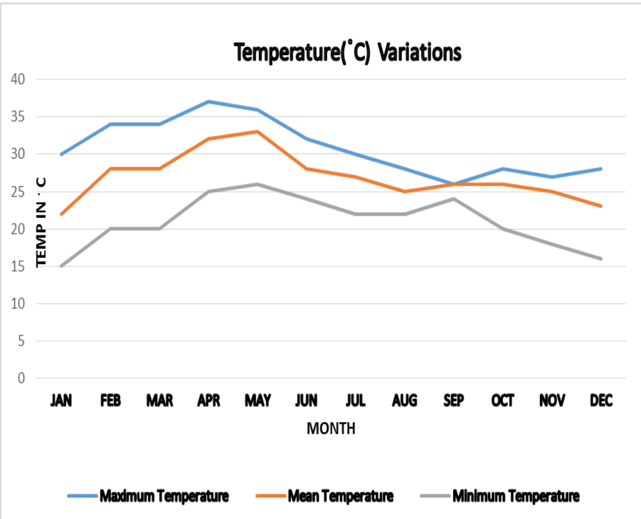

Fig 2- Temperature Variations in Study Area(WRIS)

E. Land Use/Land Cover

Land use is a description of how people utilize the land and socio-economic activity. This basin holds a variety of land cover and land use classes. Land use pattern has a long drawn effect on the economy as well as on the ecology of any area. The land use / land cover (2005-06) of Bhimabasin has shown in figure 3. Statistics of land use / land cover (2005-06) has been given in Table 1.

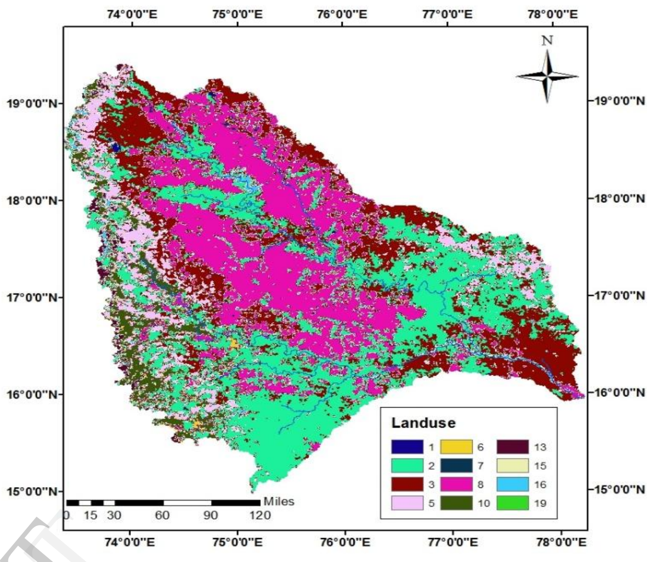

Fig 3- Land Use/Cover Details of Study Area

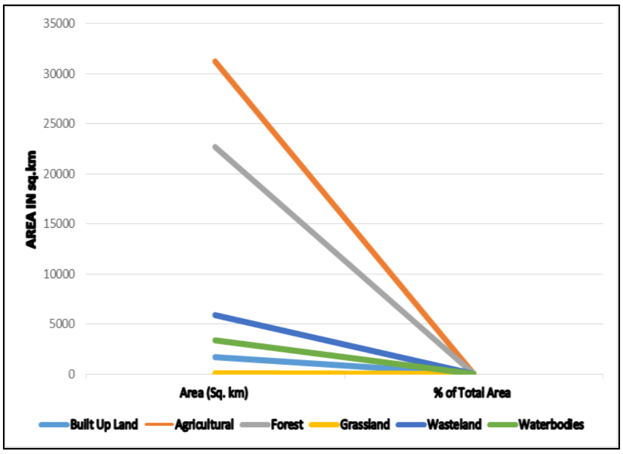

Figure 4 Land Use/Cover Details

Table 1- Land Use/Cover Details

S.no	Category	Area (Sq. m)	% of Total Area
1	Built Up Land	1712.14	2.29
2	Agricultural	31235.87	46.23
3	Forest	22729.12	40.00
4	Grassland	112.69	0.41
5	Wasteland	5893.89	7.00
6	Waterbodies	3389.78	4.07

F. Soils

Soil is composed of minerals, mixed with some organic matter, which differ from its parent materials in terms of its texture, structure, consistency, and color, chemical, biological and other characteristics. Information on the soil profile is also required for simulating the hydrological character of the basin. The important soil types found in the basin are black soils (regur), red soils, laterite and lateritic soils, alluvium, mixed soils (red and black, red and yellow, etc.) and saline and alkaline soils.

The soil texture map of the basin in Map shows the distribution of soil texture in the basin. Most area of the basin is having fine texture of soil. Based on texture major part falls under fine texture category (72.62%) with rocky and water bodies accounting for the minimum of 3.31%.Medium Texture (16.19%) and Coarse Texture (7.7%) are also found in some areas of the basin. Soil erosion is moderate in more than 56% of the total basin area with very severe erosion in 2.5% of the basin area (WRIS).

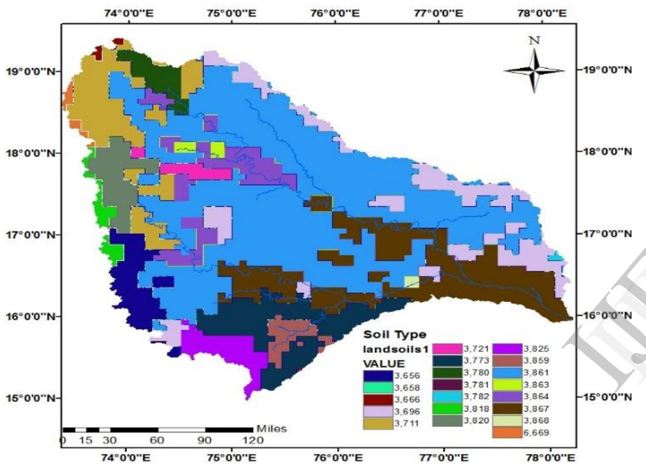

Fig 5- Soil Texture

III. DATA SETS AND MODEL SETUP

We categorize the data required for hydrological simulation of a River Basin broadly in two types-spatial data and non-spatial data. Hydrological simulation of the river basin requires certain type of data before simulation. The spatial data required by SWAT for hydrological simulation of basin are: DEM, LC/LU, SOIL MAP, and WEATHER DATA. The digital elevation model (Fig 6) from SRTM has Projection System of WGS_1984_UTM, Zone_44 N at 90 meter resolution is used. LAND COVER/LAND USE MAP of 1 km grid cell size taken from university of Maryland Global Land Cover Facility is used (Fig 3).SOIL MAP used is the FAO Digital Soil Map of the world having scale of 1:5,000,000.(Fig 5)

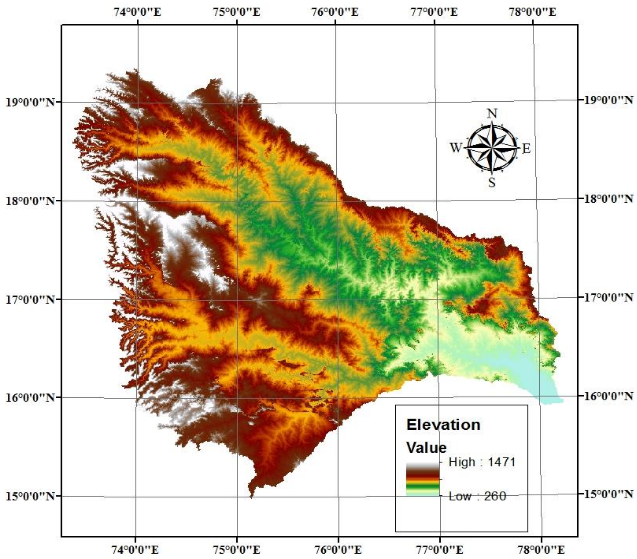

Fig 6- Digital Elevation Model of Study Area

On the same lines of Spatial Data, an extensive data set is required for non-spatial data type. There are temperature, precipitation, relative humidity data, solar radiation data, wind speed of base line (1971-2005), all these data type are at point location. Weather data used is high resolution (1° Lat x 1° Long) daily gridded temperature data set for the period 1971-2005 and high resolution (0.5° x 0.5° Lat/Long) gridded daily rainfall data for the period 1971-2005 over Indian region developed by national Climate Centre IMD Pune, India. Using the Digital Elevation Model (DEM) SWAT generates the stream network, identifies the outlet points for a given threshold value, delineates the main watershed and sub-watershed within it. In this instance, 23 sub basins are created. Land Use and Soil Grids are then overlaid and the basic units of modelling (Hydrologic Response Unit, HRUs) are extracted.

IV. METHODOLOGY

The Arc SWAT 2009 version has been used for simulations in the present study. The spatial input data layers required to run the model include digital elevation model (DEM), land use data, soil data and weather data. A 90 m×90 m DEM, which is available from Shuttle Radar Topography Mission (SRTM) of USGS has been used to delineate the boundary of the watershed and analyze the drainage patterns of the terrain. Terrain parameters such as slope gradient and slope length, and stream network characteristics such as channel slope, length and width have been derived from DEM. SUFI-2 has been used for calibration and uncertainty analysis and is capable of analyzing a large number of parameters and measured data from many gauging stations simultaneously. It also requires the smallest number of model runs to achieve a good calibration and uncertainty results and it can be easily linked to SWAT- CUP through an interface. The workflow diagram is shown in Fig 7.

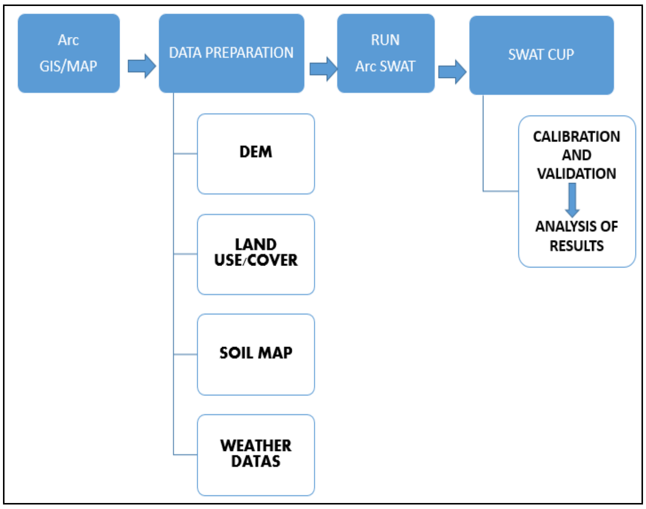

Fig 7- Workflow Diagram

V. CALIBRATION AND UNCERTAINITY ANALYSIS

SUFI-2 has been used for calibration and uncertainty analysis and is capable of analyzing a large number of parameters and measured data from many gauging stations simultaneously. It also requires the smallest number of model runs to achieve a good calibration and uncertainty results and it can be easily linked to SWAT- CUP through an interface. SWAT model has been calibrated for monthly simulated stream flows by comparing with the observed stream flows on the Y*aparla* gauge station. The model has been simulated for a period of 35 years (1971–2005). The model sensitivity, calibration and uncertainty analysis have been carried by using SWAT-CUP (calibration and uncertainty programs) interface. The model has been calibrated for selected parameters which were most sensitive. Parameter uncertainty in SUFI-2 accounts for all sources of uncertainties such as driving variables (e.g. rainfall), conceptual model, parameters and measured data (Abbaspour et al. 2004). P-factor and d-factor (Abbaspour et al. 2007) have been used to evaluate the strength of calibration and uncertainty measures in addition to Coefficient of correlation (R2) and Nash–Sutcliff Efficiency (NSE). For ideal condition, the P-factor should tend towards 1 and have a d-factor close to 0. When acceptable values of P-factor and d-factor are reached, then the parameter uncertainties are in the desired parameter ranges. In addition to these factors, goodness of fit has been evaluated by the Coefficient of correlation and NSE between the observations and the final best simulations (Moriasi et al., 2007). NSE is a normalized statistics that determines the relative magnitude of the residual variance compared to the measured data variance (Nash and Sutcliffe 1970). It indicates 1:1 line fit between observed and simulated data and is computed as:

$$NSE = 1 - \left[\frac{\sum_i^n \left(Q_{obs_i} - Q_{sim_i}\right)^2}{\sum_i^n \left(Q_{obs_i} - Q_{mean}\right)^2} \right]$$

Where, n is the total number of observations, Q_{simi} and Q_{obsi} are the simulated and observed discharges at i^{th} Observation, respectively, and Q_{mean} is the mean of observed data over the simulation period. NSE values ranges between -∞ to 1, with optimal value of 1 (ASCE 1993; Gupta et al. 1999 and Moriasi et al. 2007).

VI. SWAT MODEL SIMULATION

The calibrated and validated SWAT model has been applied to simulate hydrologic components of the Bhima River Basin for period (1974–1984). The criterion used for calibrating the model was to minimize the difference between the measured and the predicted cumulative annual stream flows and to match the predicted cumulative monthly amounts with the measured values of stream flow. The calibration of the model for stream flow was done by adjusting the runoff curve number for condition II (CN2), soil available water capacity (SOL_AWC), and the soil evaporation compensation coefficient (ESCO). Hence, these three parameters were found to be very sensitive in SWAT studies performed by Spruill et al. (2000), Santhi et al. (2001), Jha et al. (2003).The procedure was continued until the shapes of the predicted and measured stream flows were in reasonable agreement. To test the ability of the model to predict system response, the model was validated using monthly measured stream flow data for 1979 and 1983, without changing the calibrated CN2, SOL_AWC, and ESCO parameters.

VII. SWAT MODEL CALIBRATION

A. Evaluation and Performance of SWAT model predictions

A larger p-factor and a smaller d-factor should be achieved to have a better calibration and uncertainty results. The model performance has been assessed by comparing observed versus simulated monthly flows during calibration and validation periods. The efficiency criteria of coefficient of determination (R2), Nash-Sutcliffe Efficiency, and P-factor and d-factor have been used to assess the model performance. These performance indicators of the model during calibration period have been found to be 0.89, 0.81, 0.61 and 0.73 respectively, and indicated a good performance of the model.

B. Analysis of Results

The SWAT hydrological model set up for Bhima basin is executed and Model runs for IMD observed climate data is also made to calibrate and validate the model with observed flows.

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Table 2- Sensitive Parameters and their Values

Parameter Name	Initial Value	Final Value
v__GW_REVAP.gw	0.95	20.0
v__ESCO.hru	0.8	1.0
v__CH_N2.rte	0.0	0.3
v__CH_K2.rte	5.0	20.0
v__ALPHA_BNK.rte	0.95	1.0
r__SOL_AWC.sol	-0.2	0.4

VIII. CALIBRATION AND VALIDATION RESULTS

SUFI-2 method was used to calibrate the SWAT model in Bhima Basin. Some previous studies (Moriasi et al. 2007; Santhi et al. 2001) suggested that model simulation should be judged as satisfactory if R2 is greater than 0.6 and Nash-Sutcliffe efficiency (NSE) is greater than 0.5.

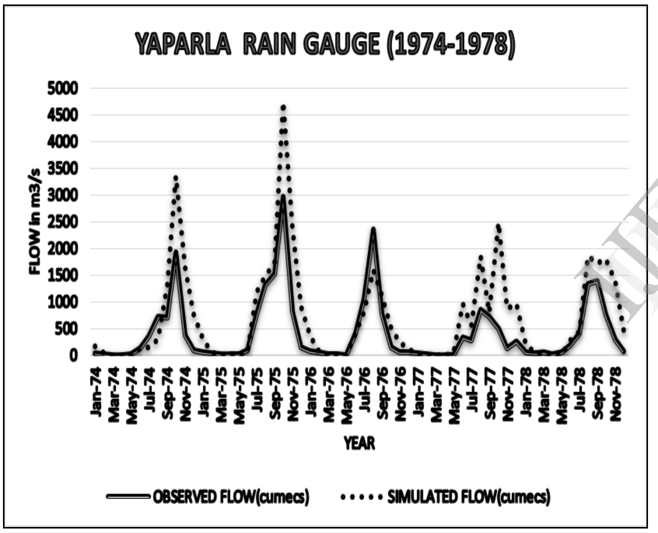

Fig 8. Observed and Simulated Result

The comparison between the observed and simulated stream flow indicated that the SWAT model accurately captured the hydrologic characteristics of the study area and reproduced acceptable monthly discharge, which was verified by higher values of R2 and NSE. The SUFI-2 results indicated that the P-factor, which is the percentage of observations bracketed by 95PPU and that the R-factor equaled 0.73 for Bhima during the calibration period.

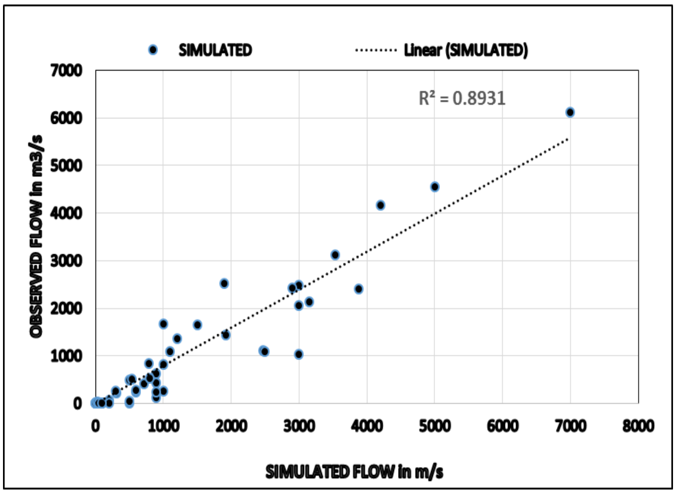

Fig 9: Scatter plot between observed flow and simulated flow during calibration period

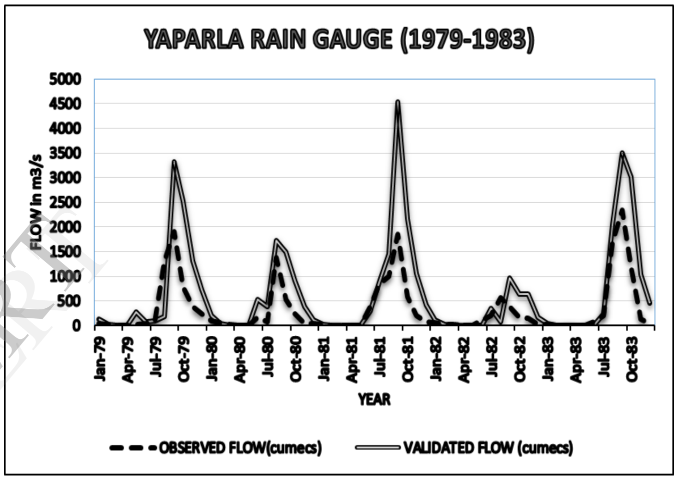

Fig 10: Comparison of Monthly Average Flow for Bhima Subbasin during Validation Period

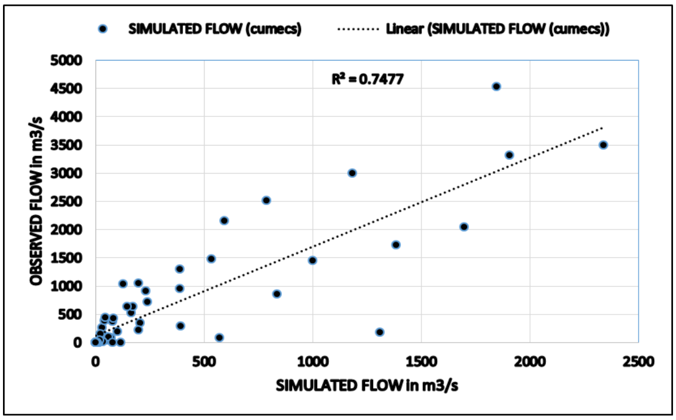

Fig 11: Scatter plot between observed flow and simulated flow during Validation Period

Table 3-Calibration and Validation Result Values

Index	Calibration (Monthly)	Validation (Monthly)
Correlation Coefficient	0.89	0.74
Nash Sutcliffe Coefficient	0.81	0.77

IX. RESULTS AND DISCUSSIONS

A set of model parameters for sensitivity analysis have been selected by referring the relevant literature (Eckhardt and Arnold 2001; Santhi et al. 2001; Lenhart et al. 2002; Whiteand Chaubey 2005; van Griensven et al. 2006) and SWAT documentation (Neitsch et al.2002). The parameters with highest sensitivity have been used to calibrate and validate the model. The results show that the most sensitive parameters are those representing the surface runoff, groundwater and soil properties. The SWAT hydrological parameters which are critical for the model performance are CN2, ALPHA BF, GW DELAY, GWQMN, GWREVAP, ESCO, EPCO, CH N2, CH K2, ALPHA BNK, SOL AWC, SOL K, SOL BD, and SFTMP. The sensitivity analysis predicted that most sensitive parameters for the USRB are Soil available water capacity (SOL AWC), Runoff curve number for moisture condition II (SCS CN2), Base flow alpha factor (ALPHA BF), Groundwater revap coefficient (GWREVAP) and Soil evaporation compensation factor (ESCO). Moreover, it has been seen that usually these are the parameters that are also found to be sensitive by other researchers such as van Griensven et al. (2006), Jha et al. (2004) and Di Luzio et al. (2004).

X. CONCLUSION

The SWAT model has been calibrated and validated using Observed stream flow data. The SWAT model has performed well during the calibration and validation periods for the Bhima basin. Ten year discharge data is divided into two equal parts for calibration and validation. Sensitivity analysis is performed to identify the key parameters affecting the flow. The flow is auto-calibrated using monthly observed and simulated flows from 1974 to 1978. Validation is carried out for flows from 1979 to 1983. The calibration result showed that there is a good agreement (R2=0.89, NSE=0.81) between the calibrated and observed monthly flows. For validation, the R2 is found to be 0.74 and NSE is estimated as 0.77.

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