SWAT Model Calibration, Validation and Parameter Sensitivity Analysis Using SWAT-CUP

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Abstract

Calibration and validation of process-based hydrological models are two major processes while estimateing the water balance components of watershed systems. The present study is conceded out with an purpose to develop a consistent hydrologic model simulating stream flow discharge with least uncertainty along with the parameters chosen for calibration. Soil and Water Assessment Tool (SWAT) model was used to replicate the stream flow Hiranyakeshi watershed situated in Maharastra southern taluks like savantadi, ajara and karnataka taluk of hukkeri consists of this watershed. Model calibration and validation were executed for both daily and monthly time periods using Sequential Uncertainty Fitting 2(SUFI-2) within SWAT- CUP using 24 parameters. Following calibration, the overall effect of each parameter used was positioned using global sensitivity occupation in SWAT-CUP. The least sensitive constraint were found to be different in either cases contrasting the most sensitive parameters. It was accomplished that the complete recognize about of the hydrologic processes taking place within the watershed and consciousness about suitable meaningful range of the parameters is essential while developing consistent hydrologic model.

Keywords*: -Watershed modeling, SWAT model, sensitivity analysis, SWAT-CUP, Land use and land cover, SCS Curve.*

INTRODUCTION

Watershed model plays a essential role to study the conclusion of the landuse and the climate change on the water resources. The characteristics of land surface area is predictable by the sympathetic of hydrological, biological, and other course of action of the watersheds by the importance of spatial variability.

The spatial information on the natural resources and the physical parameters are precious and real time, these data are provided Remote Sensing Satellites. For the watershed modelling, GIS is an useful tool. The assessment of runoff uses the remotely sensed data. This helps in development of water resources projects and suitable for soil and water conservation measures. Hydrological modelling of watershed is conceded by an withdrawal of watershed parameter using RS and GIS. The SWAT is used broadly in hydrological model.

Measurement of runoff is may be important; it is required for downpour risk management, climate, water resource planning and ecological studies, and fulfilment with cross border agreements. Understanding the flow rate of water is also required for engineering design, flood forecasting, global water balances, navigation, reservoir operations, water supply, recreation, design of waterways, irrigation planning, agricultural activities and environmental management.

Runoff estimation methods available are direct method and indirect method. Direct method involves current meter, crest stage gauge, staff gauge. Indirect method consists of SCS curve number method, Tablot's equation, Creager's equation, rational method, Unit hydrograph. It is necessary to predict the runoff of basins in order to remove mistakes in decision making and reduce the chance of inadequate design, construction or operation of water systems or other hydrologic projects, planning for irrigation, developing hydroelectric project, control of floods, water supply for drinking and domestic use, design of water ways, recreation, management of agriculture etc. Runoff data provide the basis for early warnings of situations wher sustainable development is threatened. Before undertaking a fresh water project, it is very much necessary to know how much water and what quality water is available.

Mathematical and analytical models are transformed to computer models by coding. These models have become popular in the recent years due to their efficiency with respect to economies and time taken for calculation. For each specific region best suited number of hydrological simulation model is developed. The commonly used physically based Rainfall runoff simulation models are MIKE-SHE,HEC-HMS, APEX andSWAT.

The review of SWAT in demonstrating surface water wonders is a very much perceived comprehensively utilized for watershed demonstrating specifically territories. So SWAT model is used in this investigation. SWAT-CUP was designed for automatically compute a sensitivity of model parameters with calibrate SWAT by means of the parameter optimization. A satisfactory results are obtained for the model and the model performance is achived by within the accurate results.

Objectives

The objectives of applying SWAT to Hiranyakeshi river sub-basin given below.

- To set up SWAT model used in Hiranyakeshi river sub basin to calibrate for the period 1995-2000and to validate for the period 2001-2006.
- SWAT CUP with SUFI-2 algorithm used for Validation and Calibration of the model.
- To assess the most sensitivity parameter.

STUDYAREA

Near ingli village the river Hiranyakeshi joins Ghatapraba which directs towards east. This river has semiarid catchment area. In maharastra southern taluks like savantadi, ajara and karnataka taluk of hukkeri consists of this watershed. The Hiranyakeshi watershed lies just about the latitudes 15°50' to 16°21' N and 74°00' to 74°40' E longitudes cope an region of 1233.13 km2 (Fig1). The study region ranges from 618 to 948 meters elevation (min and max respectively).

With rounded hills encomprises of intermittent valleys and wide flat terrain the land is much undulating. The main rocks in current study area are decan traps, quartzite rock also Sand stone. The region forms a evolution between greater plains to the east and hilly Western Ghats.

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Due to dehydratation of shallow water sources Scarcity of water starts throughout summer this inturn causes glitches for farming and domestic activities. For this period of summer the readily obtainable surface source gets dried up, which causes severe problems for domestic and agricultural activities. Hukkeri taluks agricultural activitis are based on subsurface water that is driven from of tube wells. In some part of this study outstanding withdrawl of subsurface water has caused lowering water table irregularity in pumping the groundwater table have been dropped in some part of the current study area.

Climatological data demonstrations that this area has mild winterhot summer crops suitable for growing are paddy, wheat, gram, Maize also pulses. This has forest land of 15%, fallow of 2%, uncultivated land of 3% and cultivated of 67% also 13% of barren land. The culturabledcommand area (CCD) has been improved by 10 to 20% as per the latest survey.

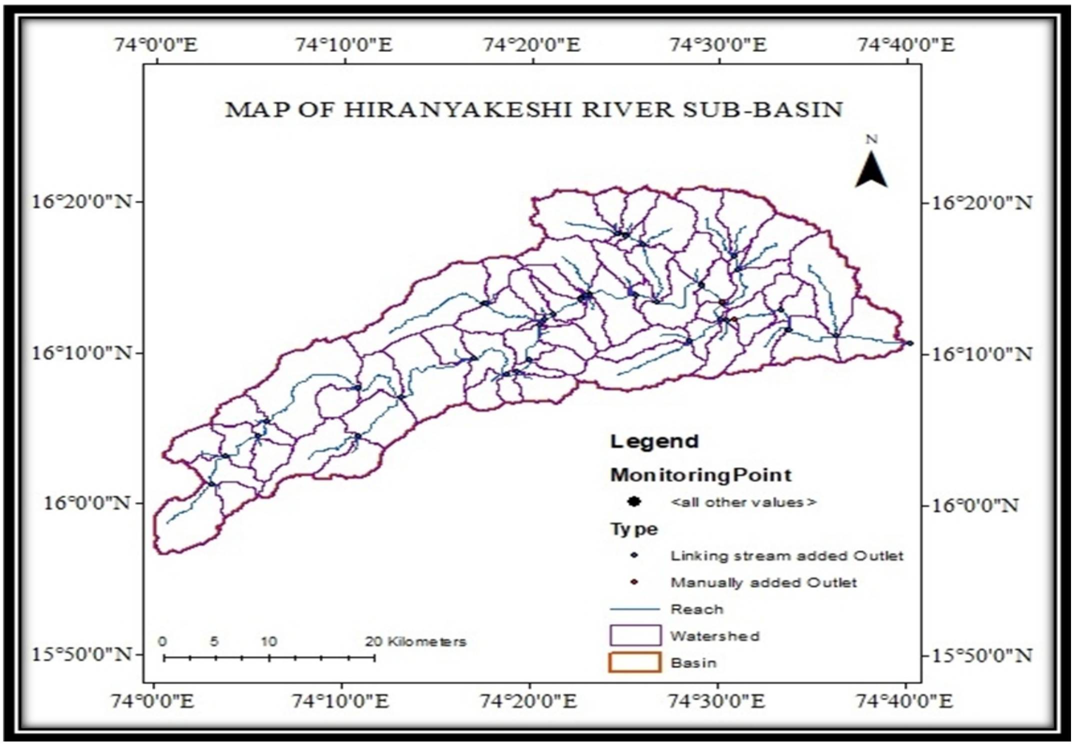

Fig1 Location Plan of Hiranyakeshi River Sub-Basin

METHODOLOGY

SWAT model is the hydrological model; it will be useful to the river catchment to compute the impact of the soil practice management to the Water Resources, Agricultural, Sediment and the Chemical yield for large complex catchment area through varying in the soil, landuse & other type management situation more than extended periods off the time.

The most important components SWAT model consist of the return flow, evaporation, surface runoff, nutrient loading, crop growth, transmission losses, groundwater flow, percolation, irrigation, reach routing, pesticide, reservoir storage, water transfer and weather. The input data required for the SWAT facsimile are used Soil map, a Land Use / Land Cover and Digital Elevation Model (DEM) are collected.

The SWAT model involves the process of the watershed delineation, Land Use / Soil / Slope Reclassification, HRUs Creation, Weather Data assimilation Writing input files and Model Simulation. SWAT model requires several of the specific information of topography, weather, vegetation, soil properties & land management practices happen in the watershed. Other extra input files are weather producer and soil database. These databases are collected of weather and soil database parameter from the weather condition station and soil.

DATA COLLECTION

Meteorological Data: (KSNDMC)
Precipitation data
Relative Humidity
Wind speed
Temperature data
Solar Radiation

Topographical data: (ISRO Bhuvan, cartosat-1, 30m)DEM Data

Geographical data: (NBSS & LUP, KSRSAC, Bhuvan, Global land30)
Soil Map
LandUse / LandCover Map

Historical Streamflow Data: (WRDO, CWC, WRIS) Observed stream flow

SWAT is the physically based model, which performs permanent moment to model used for the long-standing simulation & prediction of hydrological components, sediment and nutrient movement for the large catchment.

For the estimation of surface runoff, the SWAT model uses Yearly, Monthly, Daily and Hourly time sequence data. SWAT model uses the empirical SCS-CN is used for the calculation of Yearly, Monthly and Daily runoff. SWAT begins through the Watershed delineation, watershed delineate to the sub-basins, then sub-basin is divided toward areas of the homogeneous similarity between the Soil type, Land use & Slope and this is identified as HRUs. The SWAT model setup and effecting out of facismile is carried as shown in the flowchart (Fig 2)

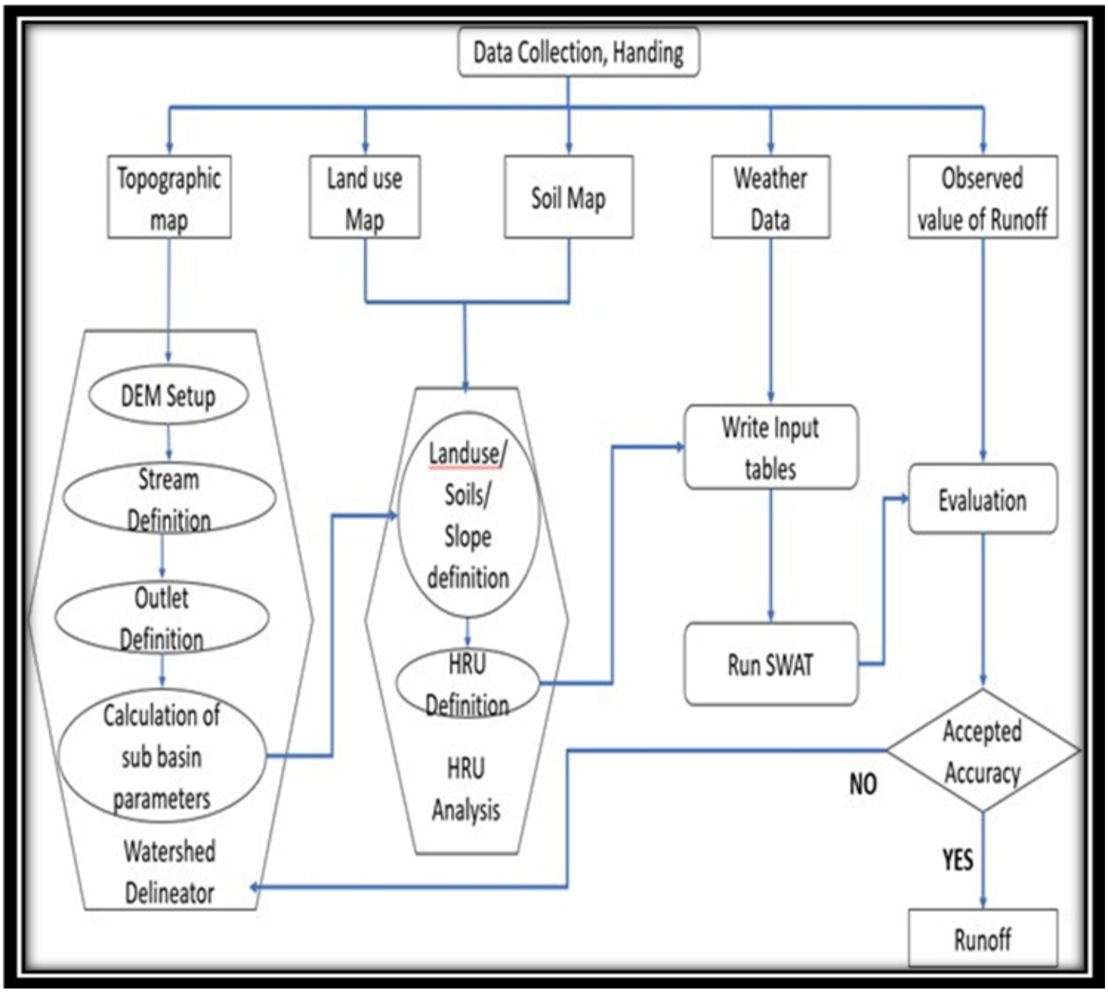

Fig 2 Flowchart Set Up and Running of Swat Model Execution

DESCRIPTION OF SWAT STEPS

Descriptions of SWAT Model

By making the use of master water balance approach expressed as (Parikh 2019). SWAT model figures peak flows also runoff volumes.

$$SW_t = SW_o + \sum (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gwd}) \quad (1)$$

i=1

all dimensions are in mm

SW_o = First reading of soil moisture content.

SW_t = Last reading of soil moisture content.

R_{day} = Quantity of Precipitation on day i

t = Duration in days

Q_{surf} =Quantity of exterior overflow on day i

E_a = Quantity of evapo-transpiration on day i

W_{seep} = Quantity of drain and diversion exiting soil form base on day i

Q_{gw} = return flow on day i

Watershed Delineation:

On Digital Elevation Models (DEMs) basis watershed delineation works. In Watershed delineation, generates the stream flow network and catchment is divided into sub-basin for the generation of outlets figure 3

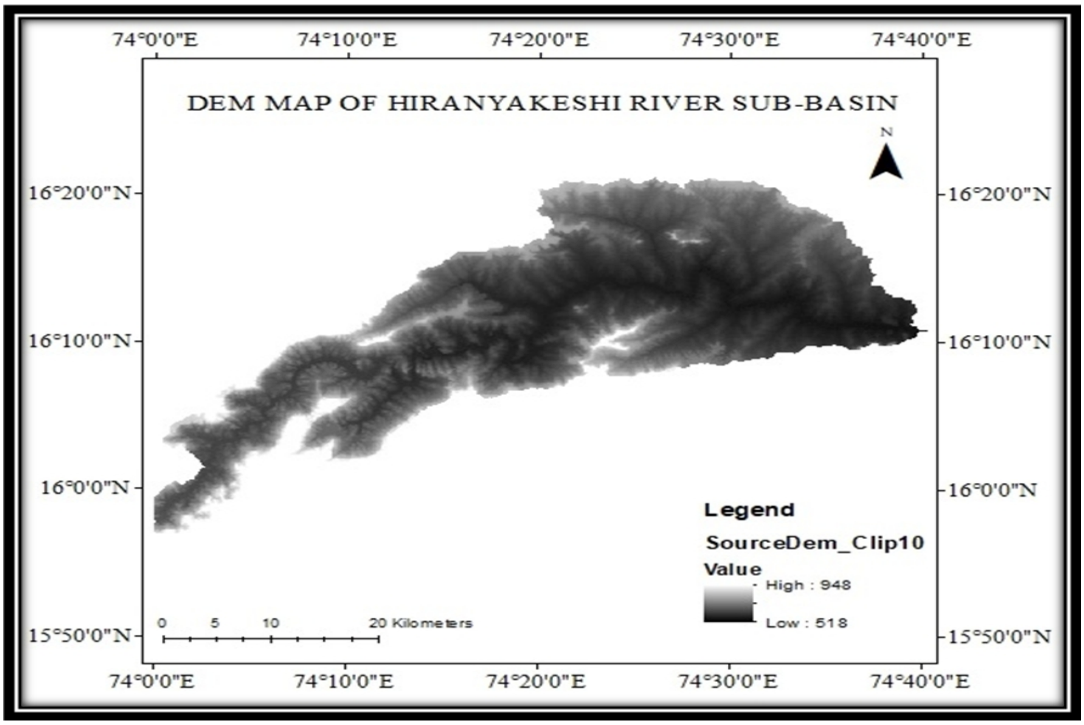

Fig 3 : Dem Plan of Hiranyakeshi River.

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3HRUAnalysis:

Area of the sub basin is divided and addicted to the HRUs. HRUs are produced with raster data. These HRUs process the sub-basin details of Land use or Land cover, soil type and Land slope. The geo-processed raster data of land usedland cover map, soil map and land slopes are considered for HRU analysis. The map details are created with a look up table and these are reclassified and overlay analysis is carried out. The maps of landuse/landcover (Fig 4), soil type (Fig 5) and land slope (Fig 6) are shown below.

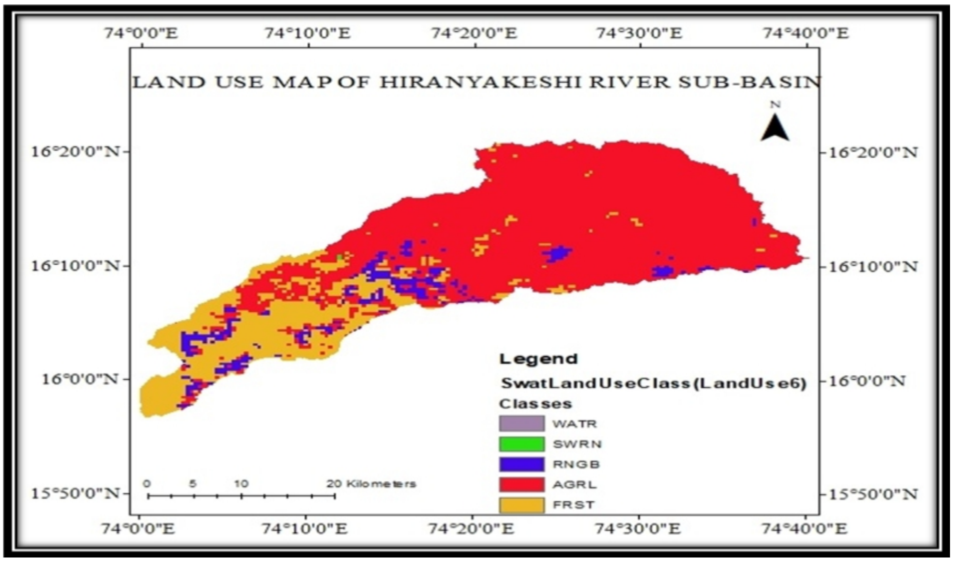


Fig 4 Land use Plan of Hiranyakeshi River.

The percentage of land use / land cover and Elucidation of the land use classes is stated below:

Table 1 Elucidation of Land use

Sl No	LULC Code	% of Area	Land Use Elucidation
1	WATR	0.05	Water bodies
2	SWRN	0.03	South Western Range
3	RNGB	5.56	Range Brust
4	AGRL	72.05	Agricultural Land Generic
5	FRST	21.559	Forest Area

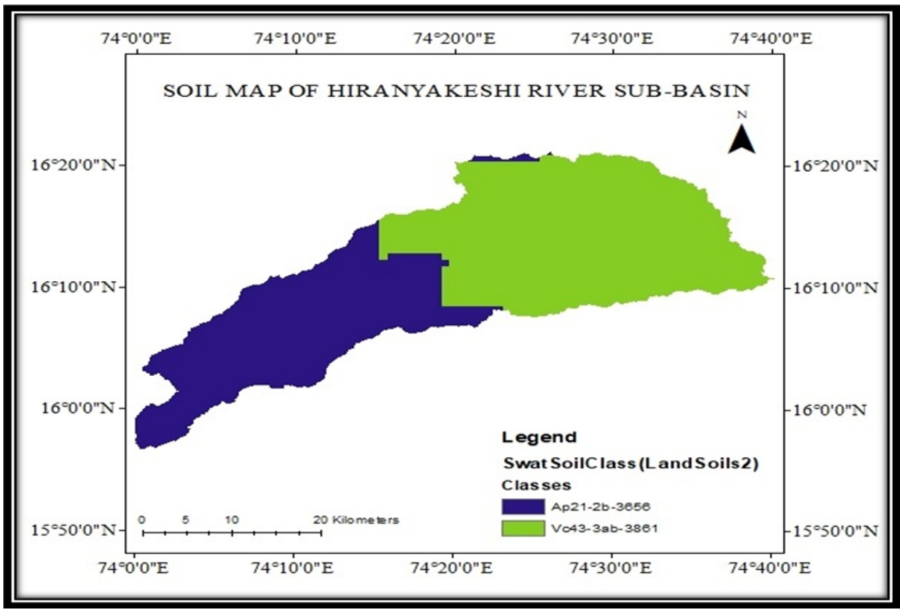


Fig 5 Soil class Plan of Hiranyakeshi river

Table 2 Elucidation of Soil Classes.

Sl No	Soil Class	Soil Name
1	Ap21-2b-3656	Sandy ClayLoam
2	Vc43-3ab-3861	Clay

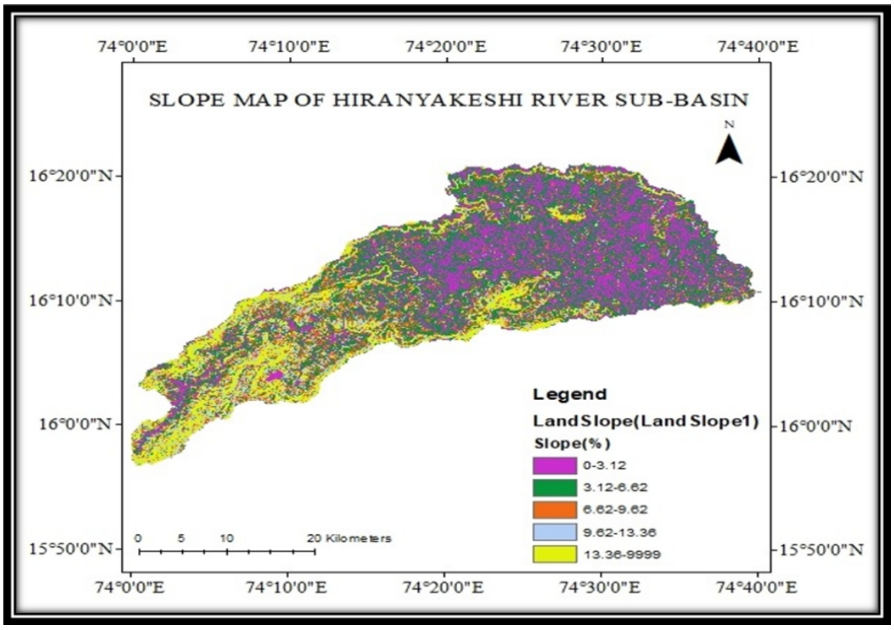


Fig 6 Land Slope Plan of Hiranyakeshi river

Weather Stations Data:

The SWAT model requires the data of Precipitation, Relative humidity, solar radiation, Wind speed and Maximum & Minimum Air Temperature. These statistics are collected in the daily time series, values for all these parameters are the records of Observed data.

From all the SWAT data input the model is executed for the time series i.e. daily, monthly and yearly for mandatory years. Beginning output flow the SWAT model give us to estimate the Nutrients, Sediment transport, Surface Runoff & Reservoir operation, Water management studies and pesticides transport. From the flow out of the SWAT model Validate and Calibrate of the model is approved.

Elucidation Of Sequential Uncertainty Fitting (Sufi)-2

Difference amongst simulated actual factors is expressed by uncertainty in SUFI-2. SUFI-2 is employed for standardization to obtain the parameter uncertainties. Homogeneous shown is unpredictability of input criterion in SUFI2 that is standardized distribution. Here uncertainty of the models output is calculated as 95PPU.Where as R factor is average thickness of 95PPU and separated by calculated data variation.

P factor is used to determinate ninty five Percentage Prediction Uncertainty.

R factor relate to the stability of uncertainty analysis.

Model Calibration And Validation

In order for accurate and actual physical procedures it's very significant to bring the calibration in the growth of any hydrological model. Here they used constraints which are highly prominent to the runoff system and those are soil parameters, groundwater criterians, and main channel criterion also the management parameters. Including warmed three years from 1992 to 1994 for the work they considered calibration period of nine years, from 1992 - 2000. Its implement the calibration technique they used 14 parameters.

Model Performance Evaluation Indices

Following are model performance appraisal by a variety of index

1) Coefficient of Determination (R2)
2) Nash Sutcliffe Efficiency (NSE)

R2 ranges 0 - 1, wherever larger desirability indicates a improved conformity.

R2 is determinated by eqn as follows (Parikh 2019).

$$R2=\frac{\sum_{i=1}^{n}(Xi+X')(Yi-Y')2}{\sum_{i-1}^{n}(Xi-X')2\ \sum_{i=1}^{n}(Yi-Y')2}$$

Where

n – number of measured data

Xi - measures and forecast data at time i,

X' - the average of measured and forecast data.

Yi - measures and forecast data at time i,

Y' - the average of measured and forecast data.

Here NSE is another modusoperandi is used. The value ranges from ∞ - 1. The efficacy of NSE can be calculated using the eqn (Parikh 2019): NSE = 1 -

$$\frac{\sum_{i=1}^{n}(Xi-Yi)2}{\sum_{i=1}^{n}(Xi-X')2}$$

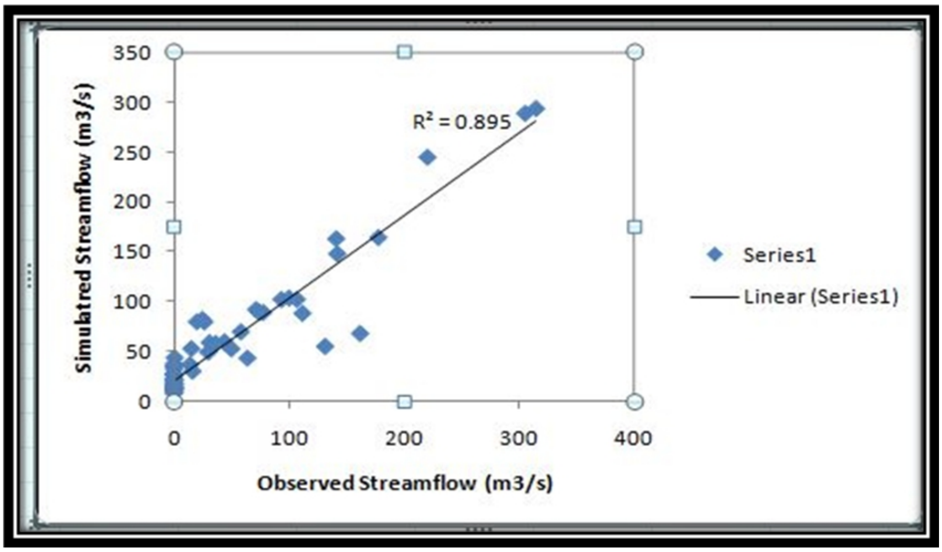
RESULTS ANDDISCUSSION

Calibration And Validation Results

For Hiranyakeshi river sub basin the Calibration of R2 and NSE desirability obtained from SWAT CUP are 0.90 & 0.85 respectively. For Validation of R2& NSE values obtained are 0.75 & 0.71 respectively.

Table 3 Calibration And Validation Results

	R^2	NSE
Calibrating (1995-2000)	0.90	0.85
Validation (2001-2006)	0.75	0.71



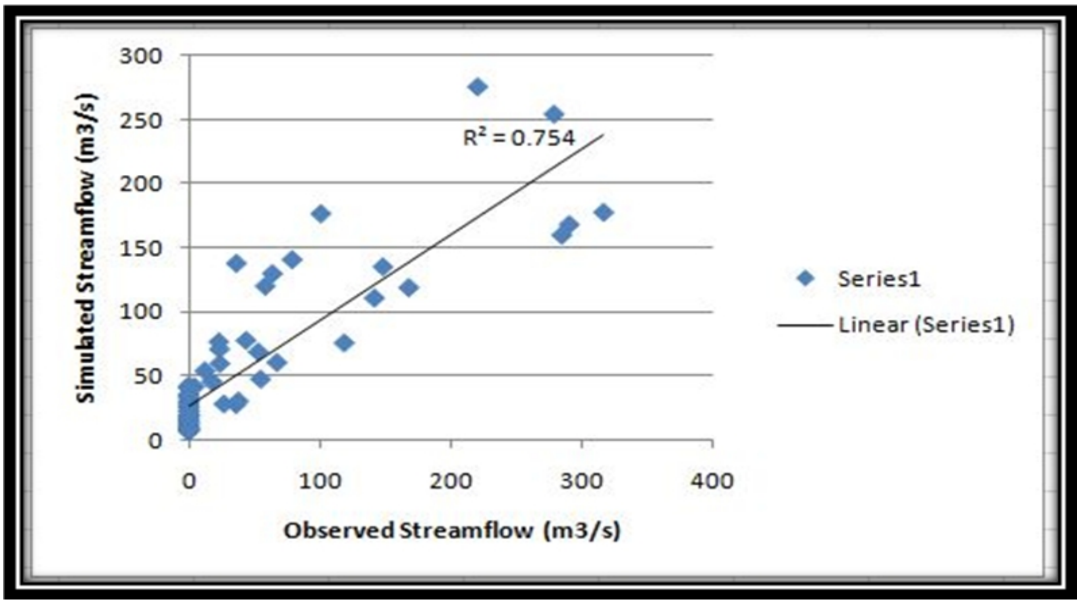
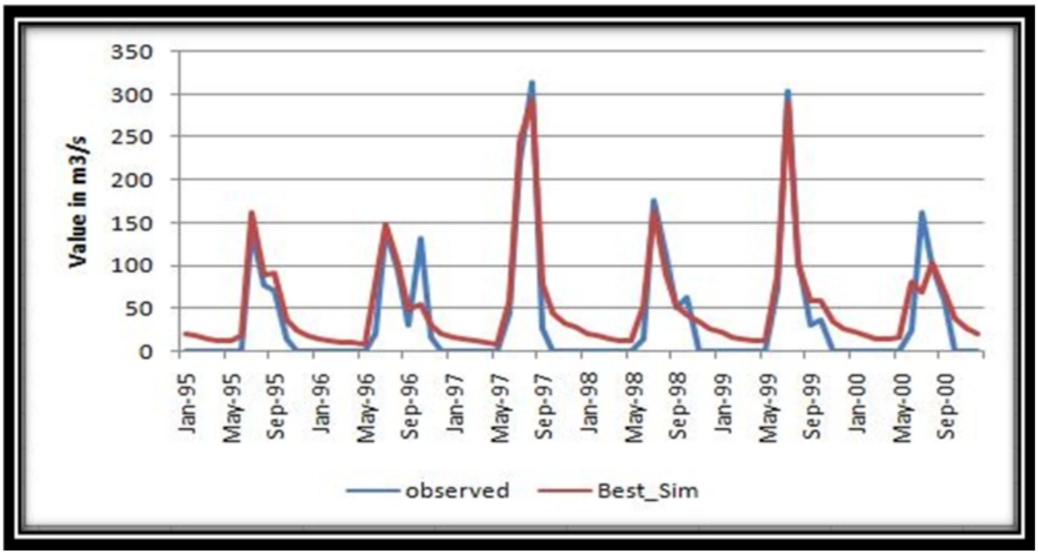


Fig 7 And 8 Scatter Graph of Daily Simulated and Observed Stream Flow During Calibration (1995-2000) And Validation (2001-2006) Respectively.

Fig 9 and 10, represents the observed and simulated stream flow are extremely close too excluding for few days. The models predictable for the runoff stream with extremely fine accuracy during the judgment. However, later on the model overestimate the stream flow, owing to unexpected raise in the desirability of stream flow. Most off the occasion the model evaluated almost the observed stream flow.



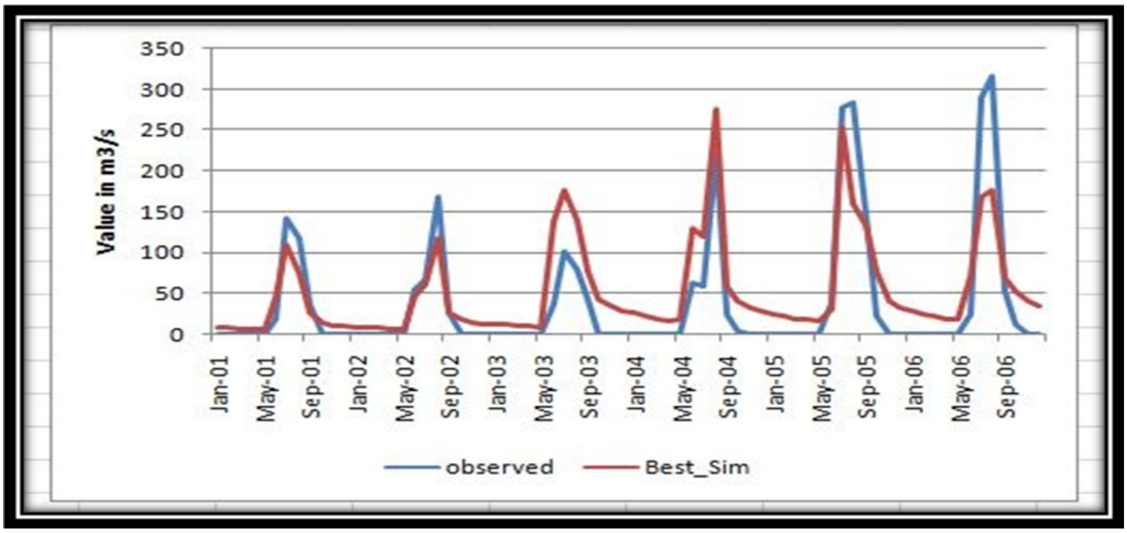


Fig 9 And 10 Comparison of Simulated and Observed Stream Flow During Calibration (1995-2000) and Validation (2001-2006) Respectively.

Sensitivity Analysis

The superlative sensitivity criterion is affects the total amount of overflow used for the contemporaneous study region is exposed. These ranks are attaining sympathetic to the object-function: the P desirability of the criterion for calibration within simulated & observed desirability.

Criterion include least P desirability has the superlative sensitivity. The superintendence of the basin for all time key aspect in estimate runoff. Here also groundwater parameter similar as Deep aquifer percolation factor (v_RCHRG_DP.gw) is initiate to be the most or first sensitive viewing that tillage operation, irrigation applications, and landuse and soil porosity of basin control overflow.

Surface runoff lagtime (v_SURLAG.hru) was the most second sensitive criterion set up.

The Threshold depth of water in the shallow aquifer for Revap (v_REVAPMN.gw) and Groundwater Revap co-efficient (v_GW_REVAP.gw) was discovered to be extremely vulnerable, a parameter relating the response of ground water surge to alteration in flowing refill. This evaluation of sensitivities shows them to facilitate the flow of regions are more over forbidden by groundwater flows.

Table 4 Sensitivity Analysis Result of Parameters

Parameter Name in SWAT CUP	P-Value	Sensitivity Rank
v_RCHRG_DP.gw	0	1
v_SURLAG.hru	0.03	2
v_REVAPMN.gw	0.03	3
v_GW_REVAP.gw	0.07	4
r_CN2.mgt	0.16	5
r_SOL_ALB().sol	0.17	6
r_SOL_BD().sol	0.29	7
r_GWQMN.gw	0.31	8
v_EPCO.hru	0.40	9
r_SOL_Z().sol	0.56	10
v_GW_DELAY.gw	0.60	11
r_SOL_AWC().sol	0.67	12
v_ESCO.hru	0.72	13
r_SOL_K().sol	0.76	14

Uncertainty Analysis

To establish the degree of uncertainty P and R factor in calibrate modusoperandi variety of P and R factor is 0 - 1, 0 - infinity. To compute efficiency of the calibrate modusoperandi to get scope the effectors turn since these optional demography are used. Parish rainfall dissimilitude rapid diversions in climatic situation the dam design and a reservoir control the hydrology of the contemporaneous current study region and participate unpredictability. In this current study, by varying limits of criterion during trial and error modusoperandi, the lower and upper limit of the criterion will reduce the unpredictability. The calibration of R and P factor were unearthed to be 0.48 and 0.24. The validation of R and P factor were unearthed to be 0.46 and 0.18. Since the P factor lies 0–1, R factor is 0-1, validation & calibrationare observed satisfying scrutinization.

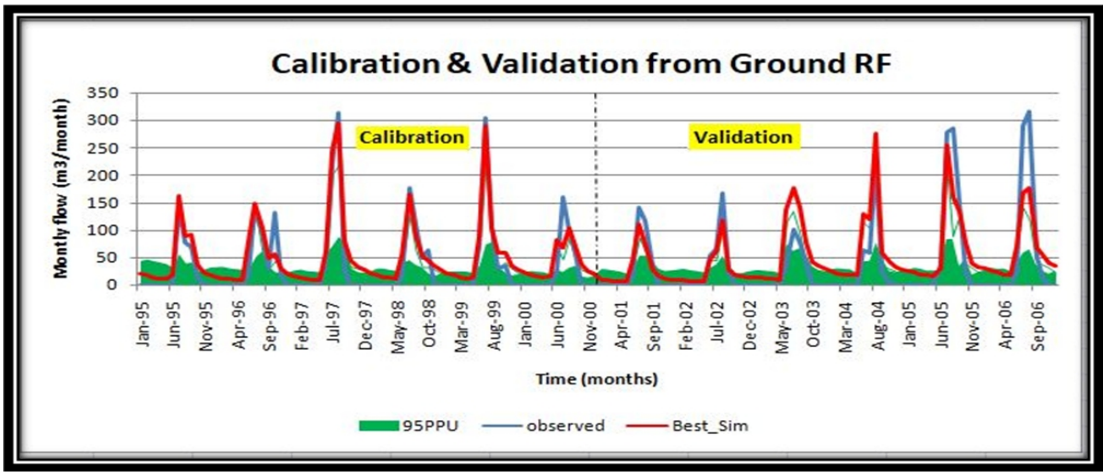


Fig 11 95% Prediction Uncertainty, Calibration & Validation Shows Output of Swat-Cup

CONCLUSION

The par annual precipitation for a total of fifteen years (1992-2006) was calculated and noted to be 950 mm and above. The paramount rainfall is procured as surface runoff i.e. 49 % tread on the heels by percolation (13 %), evapotranspiration (36 %) and deep recharge as well as tangential flow at 1% which is also manifested with the procured Average CN_2 as 64.38 stipulating better amount of overflow can be procured by opening point way. Nash Sutcliff efficiency (NSE) and R^2 values procured for calibration period 1995-2000 are 0.85 and 0.90 respectively and for validation period 2001-2006 as 0.71 and 0.75 respectively, stipulating a way better attainment model. Scrutiny of these sensitivity parameters divulged to facilitate the pair, groundwater flow and surface water features masters the stream flow in this regional area.

SWAT alongside with the RS & GIS able to be administered to estimate multiple hydrological criterion for this current study region. SWAT model is utilizable in appraise several water balance components with better accuracy.

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