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Calibration and Uncertainty Analysis of Hussainsagar Watershed using SWAT-CUP, Sufi -2 Approach

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ABSTRACT

Simulation of process-based hydrological models is a significant process and can be better interpreted by calibration and validation of these models. In the present study, SWAT model was chosen to simulate the hydrologic processes of Hussainsagar watershed followed by calibration and validation for monthly time steps using the SUFI-2 approach. Several trials were initiated to achieve a good correlation between the observed and simulated values as each objective function is sensitive to certain parameters. The goodness of fit was further assessed using the coefficient of determination (R^2) and Nash–Sutcliffe Efficiency (NS) between the observed and final simulated values. The results have shown a good correlation between observed and simulated discharge values with R^2 =0.97 and NS = 0.96, for calibration period and with R^2 =0.99 and NS = 0.97 for the validation period for monthly time steps. After performing calibration followed by validation, the influence of each parameter considered was ranked with the help of global sensitivity analysis present in the SWAT-CUP. The overall study revealed that the ArcSWAT can be used efficiently to study the behavior of an urban watershed having varied hydrology, also determine the trend in the rainfall pattern for daily and monthly periods. The results obtained have shown a good correlation and would be helpful to the hydrological community for adopting better water management practices and in designing better infrastructure.

***Key words* :** *ArcSWAT, SWAT-CUP, SUFI-2, Calibration, Validation, Uncertainty analysis*

Introduction

The rapid changes in land use and land cover especially in urban areas have led to significant changes in hydrologic processes of the Hyderabad region leading to frequent flooding in most of the parts of the city. Investigation of changes occurring in these hydrological processes due to variations in land use such as trends in rainfall-runoff patterns, streamflows, peak flow, quality, and quantity would be helpful in identifying the potential hazards due to these changes in a particular area. These investigations further aid in improving water resource management strategies thereby helping urban planners in designing the infrastructure in a better way.

Maintenance and collection of information related to water quality and quantity from numerous rain gauge stations for longer durations is a tedious and expensive job (Fekete BM, Vörösmarty CJ 2007). Currently, numerous hydrological models are being developed and extensively used to simulate hydrologic processes which include both quality and quantity of stream-flow on a sub basin-scale (Abbaspour KC, Yang J, Maximov I, Siber R, Bogner *et al.*, 2007). Every model differs from its contemporaries and each model has its own merits and demerits to its credit and is suitable for a specific application (Gayathri K Devia *et al.*, 2015). Modeling of large-scale distributed watershed models requires huge data and the availability of relevant data is a major setback and is a serious problem in hydrologic modeling across the globe (Abbaspour *et al.,* 2019). By using new tools and technologies, various distributed models are being developed for the modeling of gauged as well as ungauged basins.

Soil and Water Assessment Tool (SWAT) is a widely used hydrological model across the world (Ajai Singh et al) (Arnold *et al.,* 2012). SWAT is being extensively used for simulation of watersheds on basin and sub-basin-scale to address a variety of hydrologic and environment-related problems (Gassman *et al.,* 2014). It is a continuous and a semi-distributed process-based hydrological model (J.R. Williams et al), developed by USDA-ARS which can be used for calculation of certain important hydrologic components such as surface runoff, streamflow, infiltration etc (Manoj Jain, and Survey Daman Sharma 2014)

SWAT-CUP is a public domain computer-based program that is used for performing calibration and validation, to check the sensitivity and uncertainty of SWAT hydrological models (Abbaspour). Calibration and validation processes become extremely complex when several parameters need to be considered and numerous iterations have to be executed. The sensitivity analysis that is in built-in SWAT-CUP helps in identifying sensitive and non-sensitive parameters, such that the number of parameters to be considered can be abridged. As a result, all those non-sensitive parameters are ignored while all those parameters that have shown significant influence were considered and ranked (Srinivas G and Gopal M Naik 2017).

The main objective of the present study is to generate a hydrologic model using ArcSWAT for small urban watersheds with limited available data, calibrate its performance for a certain period, and then validate. In the present study, results obtained from ArcSWAT were calibrated and validated in SWAT-CUP followed by a sensitivity analysis using SUFI-2 (Sequential Uncertainty Fitting) approach.

Materials and Methods

Study Area and Data Input

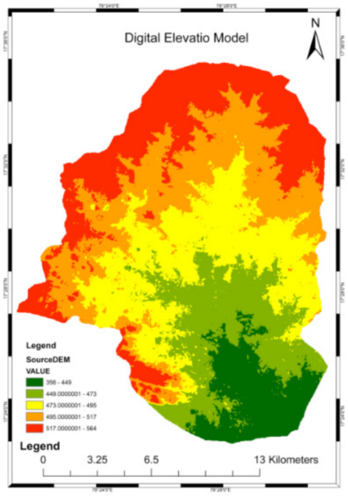
The Hussainsagar catchment area is around 287 sq. km and it falls under six sub-watersheds viz. Dhulapally, Bowenpally, Banjara Hills, Kukatpally, Yusufguda, and Hussainsagar Downstream catchments. The highest peak in the catchment is at 642 m which lies north of Nizampet while the lowest is about 500m at the confluence of the stream outlet adjoining with the Musi river downstream. Hussainsagar Lake located in the central part of Hyderabad spreads across 540 hectares but due to unprecedented growth and infringements presently the area has shrunk to 450 hectares. The majority of the water that enters into the Hussainsagar watershed is from the Kukatpally Nala, but during monsoon season most of the water that enters into the lake is due to domestic sewage and industrial effluents (A. Sridhar Kumar,Y.Seeta, Dr. P.L.K.M. Rao, Prof. P. Manikya Reddy. (2015). The sources of the data input are given in Table 1.

Digital Elevation Model

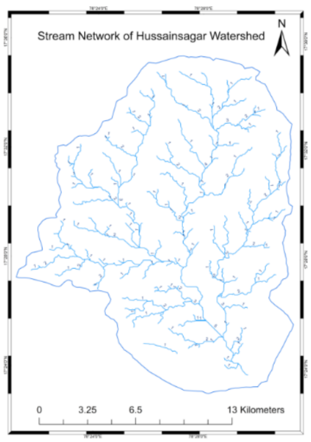
The digital elevation model is the first input data given to run the SWAT model. In the current study, ASTER DEM with 30m resolution was acquired from USGS Earth Explorer and then it is clipped to get the area of interest as shown in Fig. 1(a) and the stream network was generated in ArcMap as shown in Fig. 1(b). Based on input DEM the ArcSWAT automatically demarcates the watershed into various

Table 1. Source and Description of Input Data

Data	Source	Spatio-Temporal Resolution	Remarks
Topography	USGS Earth Explorer	30 m	ASTER DEM
LULC	Landsat-8	30 m	Land-use Classification
Weather Data	NASA Power data	Daily	Rainfall, Maximum, Minimum Temperature, Solar Radiation, Wind Speed, Relative Humidity
Soils	SOIL_WATERBASE	-	Soil Classification
Precipitation Data	IMD, Hyderabad	Daily	Daily rainfall from Self Recording Rain Gauge (SRRG)



1 (a)



1 (b)

Fig. 1 (a) Digital Elevation Model of the proposed study area, **1 (b)** Stream Network of the proposed study area

sub-watersheds and in the present study the entire area has been divided into 6 sub-basins.

Land-Use and Land Cover Classification Data

LULC data is the second input given to run the SWAT model. For the current analysis the study area was classified into five major classes viz. Water, Urban settlements, Vegetation, Low vegetation, and Barren land based on their land-use for further analysis which is represented in Fig. 2. There are two methods of image classification and in the current study, a combined approach has been considered where both supervised and unsupervised classification techniques were used to get the Land Use Land Cover map for the proposed study. In this approach, firstly we classified the proposed study area using the unsupervised method by considering 100 classes. Once these 100 classes were automatically generated then recoding of all these classes was done manually for better accuracy especially when there is a varied and complex terrain. During the recoding process each and every class was visually compared and checked manually by comparing the satellite image for its spectral signature and then classes related to the same feature class were merged and finally, they were reclassified into 5 major classes as shown in Fig. 2.

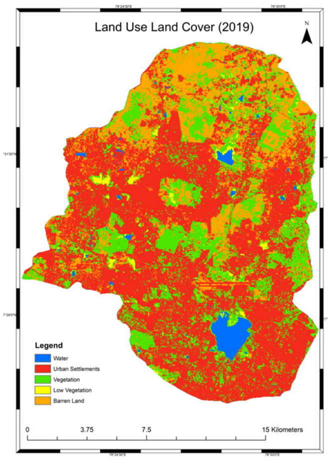


Fig. 2. LULC of Hussainsagar Watershed during 2019

Soil Data

The Soil map is the third input to run the swat model, and it represents the geographical and spatial distribution of numerous soil types and their characteristics present in a particular area. In the present study, the soil map has been freely downloaded from the https://swat.tamu.edu/ website and clipped to get the area of interest as shown in Fig. 3, and it was observed that major soil class type i.e. "clay-loam" and "sandy clay loam" were dominant for the entire study area.

Swat Model Run

Digital elevation data, soil, meteorological data along with land-use land cover information are the prerequisites needed for running the model in ArcSWAT. Once the input parameters are given the first step involved in running the SWAT model is the watershed delineation and computation of slope by using the digital elevation model. The results obtained in this preprocessing step are useful to de-

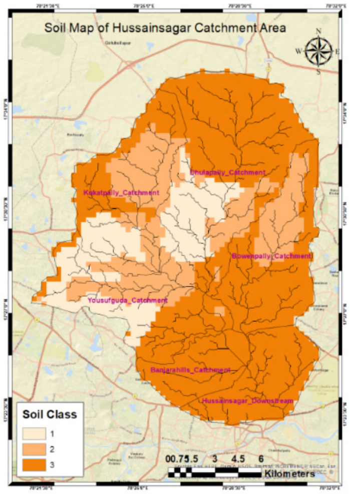


Fig. 3. Soil map of Hussainsagar watershed

termine the flow direction and flow accumulation of the proposed study area.

HRU Analysis

The Hydrology analysis is an important step in SWAT modeling and by using the combined land-use, and land cover classes information, soil and slope data the hydrologic response units (HRU's) were created by using distinctive combinations of the above classes. In the present study a total of 6 sub-basins and 33 HRUs were created by giving threshold values of 15% to land-use, 12% to soil, and 15% to the slope.

Writing input tables for weather stations –

Once all sub-basins, HRU's are well defined, input tables were created by taking relevant values from meteorological and IMD data for further analysis. The Meteorological data required for swat modeling includes solar parameters such as mean, minimum, and maximum temperatures, wind speed, and relative humidity which were obtained freely from NASA power data viewer while the precipitation data required was procured from IMD, Hyderabad.

Running Swat Model

In the present study, the SWAT model was run for 22 years i.e. from 1998 to 2019 for monthly as well as daily periods having an initial warm-up period of 2yrs.

Swat Calibration and Validation

SWAT Calibration and Uncertainty Program (SWAT-CUP) is an interface that has been developed to accomplish calibration, validation and uncertainty analysis for results obtained from SWAT modeling. There are 4 approaches in SWAT-CUP namely SUFI2, GLUE, ParaSol, McMc, and PSO. In the current study, SUFI 2 approach was considered, and results obtained from the SWAT modeling were calibrated for a period of 15 years i.e. from 2000 to 2014 and then validated for the next 5 years i.e. from 2015 to 2019 for the monthly time step.

In this process, certain relevant parameters were selected, and by assigning some random lower and upper values initially the calibration process is executed to check for uncertainties. Based on results obtained parameter ranges/values were altered and several trials were initiated until best-fitted values were obtained. Once best parameters have attained those values were fitted into the SWAT_CUP database for performing simulations for the monthly time step. The objective function R^2 was used as a probability measure for rainfall-runoff modeling using the SUFI-2 approach between observed and predicted stream-flows (Boini Narsimlu et al 2015). The performance of the model was estimated using ten influencing parameters given in Table 2 and also sensitivity analysis has been initiated to determine which model parameters had a paramount influence on hydrologic processes.

Results

SWAT Model output

SWAT has been used in the present study to simulate stream-flow of Hussainsagar watershed and the model has been executed to study the effect of LULC changes on the basin hydrology for 22 years duration i.e. from 1998-2019 for daily as well as monthly periods with an initial warm-up of 2 years i.e. (1998-1999). The simulation details for monthly as well as daily periods are depicted in Fig. 4 and the results obtained were saved for calibration and validation.

Calibration and Validation in SWATCUP

In the current study, the model was calibrated for 15 years duration i.e. from 2000 to 2014, and then validated for next 5 years duration i.e. from 2015 to 2019 considering 10 hydrologic parameters 5 objective functions. Initially, utmost care was taken to assign lower and upper limits to each of the 10 hydrologi-

Table 2. Selected SWATCUP parameters for present study

Sl.No	Parameter	Description
1	SURLAG	Surface runoff lag time
2	GWHT	Initial groundwater height (m)
3	REVAPMN	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)
4	CH_K2	Effective hydraulic conductivity in the main channel
5	GW_REVAP	Groundwater "revap" coefficient
6	GW_DELAY	Groundwater delay (days)
7	SLSUBBSN	Average slope length
8	HRU_SLP	Average slope steepness
9	ESCO	Soil evaporation compensation factor
10	CN2	Soil conservation service run-off curve number

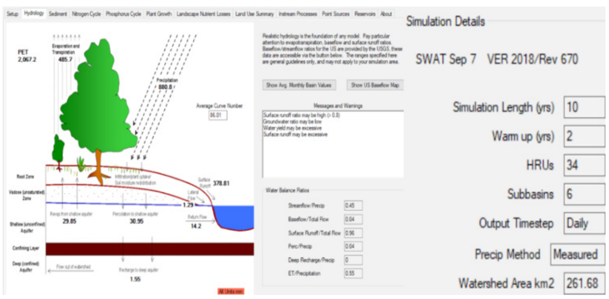


Fig. 4. Simulation Details

cal parameters that were considered and optimal iterations were instigated to attain the best-fitted parameters. To minimize uncertainties several attempts were made until best-fitted parameters and satisfactory results were attained between observed and simulated values for both validation and calibration processes.

It was observed that by keeping objective functions and selected parameter ranges the same for calibration and validation processes, the model has produced almost similar results for different indices. The objective functions viz. coefficient of determination (R^2) and Nash-Sutcliffe (NS) efficiency, P-factor, R-factor, and PBIAS were selected for comparison between calibrated and validated values. From the results, it was observed that the majority of values obtained during the calibration and validation period were well within the boundaries of 95PPU for monthly time step. NS value is a measure of the predictive power of the calibrated model, and a resultant value of 1 for NS indicated a perfect match between calibrated and validated periods. R^2 measures the strength of linear correlation and a value of 1 indicates a perfect linear correlation between calibrated and validated values (Shahnaz Khatun et al). The model has shown an excellent correlation for monthly time step as represented in Table 3, thus indicating a good fit between calibrated and validated values.

PPU Plots

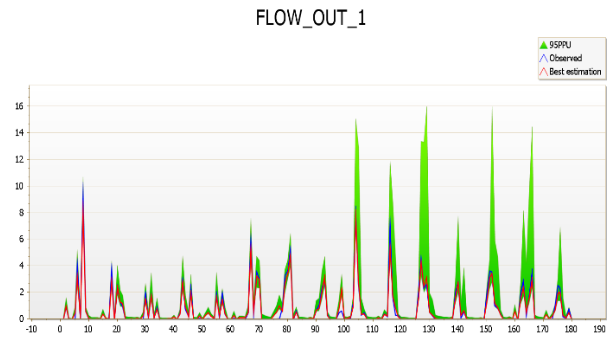
Uncertainty analysis generally refers to the propagation of all model input uncertainties (mapped in the parameter distribution) to model outputs. Uncertainties in input generally arise due to lack of acquaintance on physical model inputs such as climate, soil, and land-use, to model parameters and model structure. Identification of all acceptable model solutions in the face of all input uncertainties can, therefore, provides with model uncertainties expressed in SWAT-CUP as 95% prediction uncertainty (95PPU) (Karim C. Abbaspour et al). Keeping all conditions, the same for calibration and validation, the model has given good results and this approach of comparing two different simulations helps in a better understanding of the assessment of model uncertainties (Sushant Mehan et al 2017). The 95 PPU plots obtained for monthly discharge values for 500 iterations are shown in Fig. 5 (a) and 5(b).

Dotty Plots

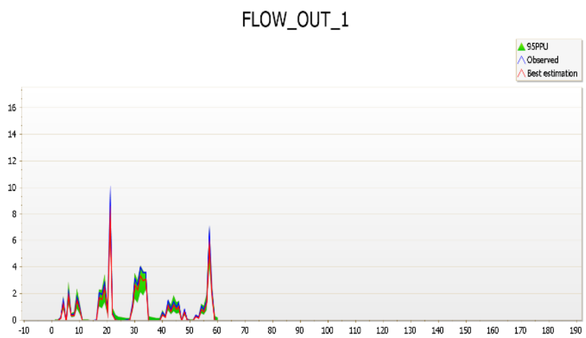
Dotty plots map the model parameters and objective

Table 3. Comparison of Indices for Monthly Time Step

Method	P-factor	R-factor	R^2	NS	PBIAS
Calibration (2000-2014)	0.41	0.80	0.97	0.96	3.3
Validation (2015-2019)	0.70	0.38	0.99	0.97	1.5



5 (a)



5 (b)

Fig. 5a. Plot depicting observed and best estimation values for calibration (2000-2014) 5(b) Plot depicting observed and best estimation values for validation (2015-2019)

functions and helps in identification of the relative sensitivity associated with each parameter and its influence on the objective function (Wagener T, Kollat J 2007). This process also helps to define a new range of values for the chosen parameters which could be further used for the next iteration level. The sensitivity of each parameter is assessed by observing the impact of objective functions using dotty plots. It is observed from the results that sensitivity is low for parameters that are disorganized and scattered while the sensitivity is high if dotty plots followed a specific trend. It was observed that even a slight change in CN2 value had the greatest influence on objective functions unlike other parameters for monthly data thus indicating it to be the most sensitive parameter. In the present study, it is observed that "CN2" was found to be the most sensitive parameter which was illustrated in Fig. 6 (a) & 6 (b).

Sensitivity Analysis

The global sensitivity analysis has been carried out for the identification of the most sensitive hydrologic parameter concerning the changes in objective function values. Table 5 represents the most sensitive parameter which is in order of 1 to 10 based on P-value and t-Stat for the monthly time step. From the sensitivity analysis, CN2 was found to be the most sensitive parameter while other parameters were found to be insensitive and had very little significance on stream-flow simulations.

Conclusions

Hydrological Predictions play a vital role in anticipating natural calamities and their influence on the hydrological regime more so in urban context experiencing frequent changes in land-use patterns. Calibration and validation of these models help in assessing uncertainties present in the model. From the analysis, it was observed that simulation results have shown a good accuracy between measured and simulated flows for monthly timestep. Thus, the

Table 5: Comparison of Global Sensitivity

Parameter Name	t-Stat Calibration	P-Value Validation	t-Stat	P-Value
1: GWHT	-0.33	0.74	-1.46	0.14
2:CH_K2	0.30	0.77	0.02	0.98
3: ESCO	-14.06	0.00	0.73	0.47
4: SLSUBBSN	1.83	0.07	-0.87	0.38
5: HRU_SLP	-3.73	0.00	-1.91	0.06
6: REVAPMN	1.05	0.29	1.26	0.21
7: SURLAG	-0.24	0.81	1.61	0.11
8: GW_REVAP	2.64	0.01	1.01	0.31
9: GW_DELAY	0.10	0.92	11.66	0.00
10: CN2	-38.30	0.00	36.44	0.00

Parameters for Monthly Time Step

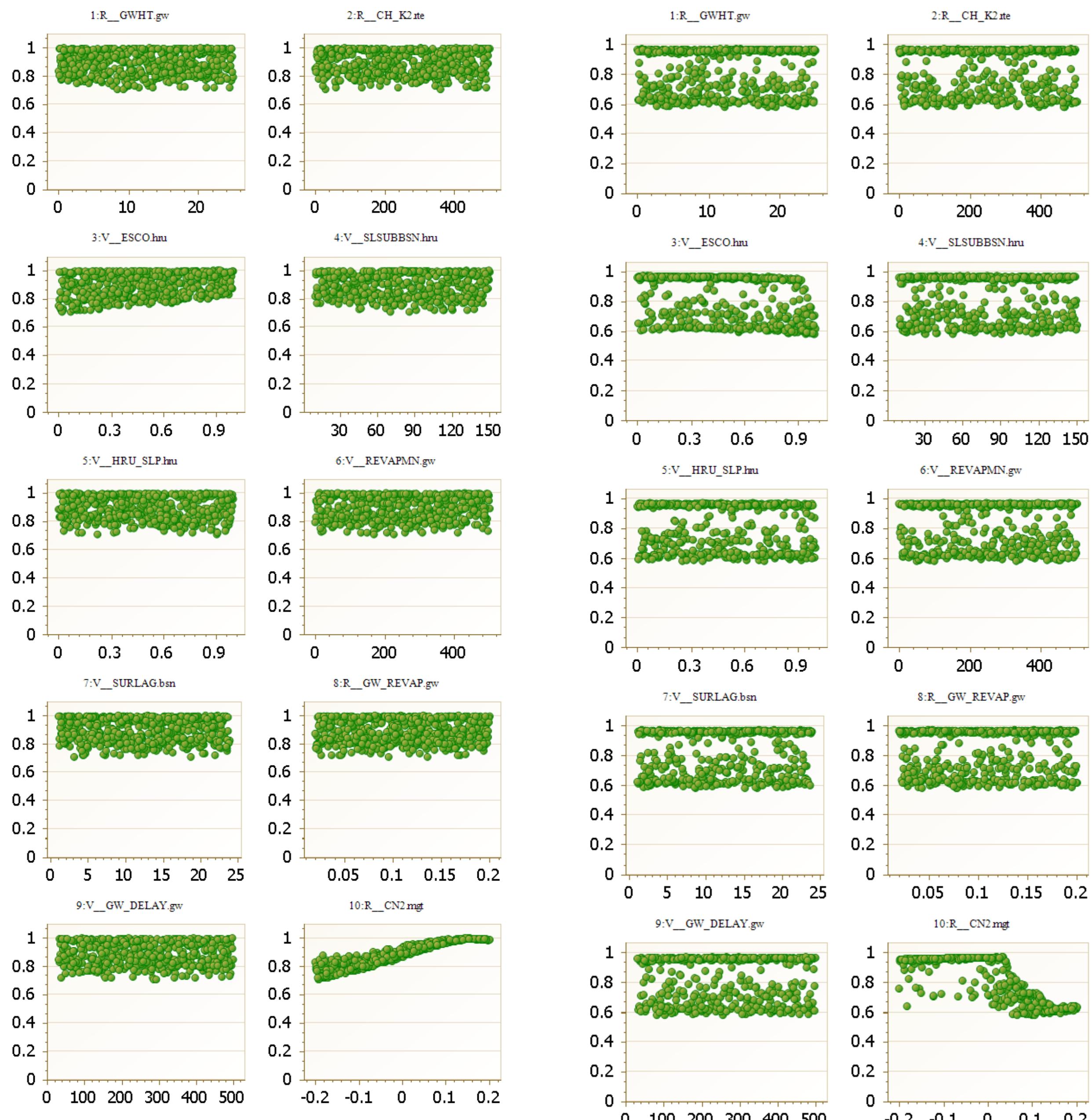


Fig 6(a) **Fig 6(b)**

Fig. 6(a) (b). Comparison of Dotty plots for Calibration and validation on monthly time steps.

calibrated model can be used further to assess the impact of land-use land cover changes on basic hydrology also the results would help deal with better water resource management practices. It is further suggested that in future approaches more parameters need to be included in model calibration such that inconsistencies present in the basic hydrology could be curtailed thereby helping the water resource communities in forecasting extremities well in advance.

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