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Quantitative Hydrological Analysis Of West Banas River Basin, India

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Abstract **-** Detailed hydrological analysis is carried out for the estimation of peak discharges at various locations of the basin and to assess the impact of factors that are driving the temporal change. West Banas basin has experienced frequent flooding with increased magnitude in last two decades. The goal of study is to accurately assess the response of catchment to the extent possible by developing different SWAT models specifically for monsoon months and the flooding years. Extraction of the basin and sub-basins, stream network is carried out on GIS platform. The entire West Banas River basin has been subdivided into 23 sub-basins. SWAT model is developed using rainfall and discharge data of 32 years (1987-2018) The calibration results reveal a good performance of the model in streamflow simulation as indicated by the values of performance evaluation indices-R^2, NSE and PBIAS. Different hydrological models are developed based on calibration of model using seasonal data such as monsoon and non-monsoon months as well as considering only flood, moderate or drought years. The model performance for each type of calibration scheme is analyzed and compared to determine optimum approach of seasonal calibration. The model developed for monsoon months produced better output in comparison to the models developed for all season months and non-monsoon months. Similarly, the model developed for flood years months gave better results in comparison to the models developed for moderate flood years and drought years. It is concluded that better flood analysis calibration must be carried out only using monsoon data.

Keywords**:** Flood; SWAT; Calibration; Monsoon

1. Introduction

In small basins of semi-arid climatic regions, it has been observed in recent past that there has been surge in the occurrence of flash floods with increasing frequency and magnitude. Such events of flash flooding in these basins result in disruption of transport network for extended period besides the enormous loss of life and property. The major portion of the effected region of present study overlaps with the West Banas basin in India, a relatively small non-Himalayan basin having semi-arid climatic conditions. Due to climate and land use change, hydrology of the area has witnessed significant changes leading to frequent flooding. Dhanera taluk in Banaskantha district of Gujarat (India), which is part of study area, recorded 235 mm of rainfall in 6 hours on July 24, 2017 [1, 2]. There was flooding for extended period resulting in 224 deaths, between 01 June to 31 July 2017 in Gujarat only [3].

Due to frequent flooding in recent past in the years 2006, 2015, and 2017, it has been observed that the water level in a few major railway bridges crossed the danger level and various minor bridges were not sufficient to cater the discharge. In 2017 Jodhpur-Jalore-Samdari Railway section was closed for all type of traffic from 24 July 2017 to 3 August 2017. During this period 05 national highways, 153 state highways and 674 other roads were closed for the vehicular traffic [4]. This region also witnessed the flooding during monsoon of year 2004, 2006 and 2015. Fig. 1 shows the effect of flood on embankment under railway track in year 2017.

Fig. 1: Washed out embankment under railway tracks during 2017 floods.

Railway Bridges were constructed more than fifty years back and since then no hydrological analysis has been done in view of the changed land use and climatic conditions. The enormous loss of life, property and infrastructure network due to floods show that there is need for proper basin management supplemented with adequate technical knowledge of hydrological response of the basin to high magnitude rainfall events. To understand the hydrological behaviour, it is important to assess the impact of factors that are driving the change in response of these sub-basins. Various studies have pointed out that the possible reasons are generally alteration in land use and landcover due to human intervention, changed agriculture practices, change in global climate due to global warming as well as increased sediment runoff into the streams. Global change is expected to increase the risk of floods in coming decades, with more people settling in floodplains, whereas climate change is likely to increase the frequency of intense rainfall events and consequent floods [5].

Flooding events have caused sizeable loss to economies, societies, and ecological environments round the world [6] and approximately 40 % of the losses originating from natural disasters are caused by the floods [7]. To date, few numerical models are able to simulate hydrological processes at basin scale at a reasonable time scale to describe these flash events with accurate details [8, 9]. This emphasis the need to assess the hydrological response of basin, as accurately as possible, for proper hydrological management at basin level to moderate the effects of such events.

Presently no systematic hydrological analysis of the study area has been reported in literature specifically in view of the monsoon period and flood years. Therefore, hydrology of the affected regions mainly West Banas basin needs to be re-evaluated especially for the extreme events causing floods. This study is an attempt for detailed hydrological analysis of the affected basin for the estimation of peak discharges at various locations of the basin by SWAT model development. In order to determine optimum calibration scheme for prediction of change in hydrological behaviour of the basin, attempts are made to develop multiple models considering variations in data utilized for calibration purpose. As wash outs of the embankment under Railway tracks were observed adjacent to the existing bridges, estimation of peak discharges at important locations will help Indian Railways to take remedial measures by re-designing the bridges for additional spans or for raising the height of bridges, wherever the existing bridges waterways are found insufficient to cater the estimated future peak discharges.

2. Study Area

The West Banas River originates from Aravalli hills at Pindwara in Sirohi district of Rajasthan at an elevation of 372.5 m above mean sea level. It descends in a South- Western direction through Rajasthan state and travels through Banaskantha and Mehsana districts of Gujarat. Finally, it drains into little Rann of Kutchh near Gulf of Cambay (Arabian sea). The Banas basin is situated between 23° 30' and 24° 55' north latitudes and 71° 15' to 73° 15' east longitudes. Saraswati and Luni basins form the Southern and Northern boundaries of this basin respectively and the Aravalli hills form its eastern extremity.

The Banas drains an area of 4970 km^2 out of which nearly 38% lies in Rajasthan state and remaining 62% falls in Gujarat state. Sipu is the only right bank tributary of Banas river which drains into the main channel. There are 6 tributaries on the left bank of Banas River namely Batria, Sukli, Sewaran, Suket, Balaram and Khari which drain into the main channel. Hence the draining system on the left bank of the Banas River is more extensive as compared to the right bank area. The Sipu dam and Dantiwada dam are the major projects in the catchment areas of West Banas basin. The average annual rainfall of the Banas basin is 768 mm. The maximum elevation of basin is 1695 m above mean sea level at Mount Abu. The main soil types are clay loamy and sandy clay soil. The study area is shown in Fig. 2 (i).

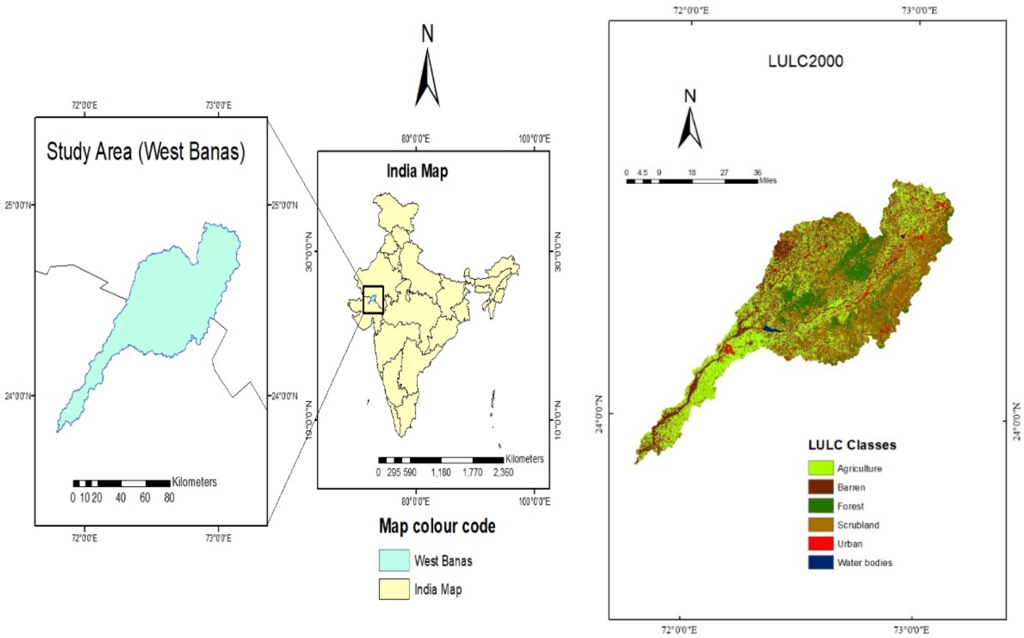

Fig. 2: (i) Study area map (ii) LULC map of study area for year 2000.

3. Methodology adopted for the study

Quantification of hydrological extreme events such as floods is essentially required to the local authorities as well as researchers to understand the present pattern and potential risks of related disasters. It is advantageous to use long term observation data to measure the trends of hydroclimatic extremes for a specific region, because it is the most reliable source for understanding the hydro climatic system [10]. However, in many regions, the availability of reliable long-term observations remains a strong limitation [11]. Moreover, reliable long term hydrological data of discharge and sediment load are scarce as compared to climate data. Therefore, hydrological modelling can be used to simulate and understand the response of catchment to the extreme hydrological events. Also some of the studies have evaluated impact of land use-landcover changes on the hydrological response [12]. In this study, SWAT model is used to analyze the streamflow and flood forecasting. Major deficiency of SWAT model is its fluctuated model simulation and efficiency performance in dry periods and the wet seasons. Output of SWAT models has been reported to be unreliable in varying seasons. This emphasizes the need to conduct further research to improve calibration of SWAT model based on variations in data set used.

Some of the studies based on calibration for dry and wet periods of the year, show different model performance for the different periods. Sensitivities of dominant parameters of SWAT during calibration were altogether different between dry and wet periods [13]. Model efficiency in the dry period was consistently lower than that in the wet period [14, 15]. Therefore, research for the basin required to reflect seasonal hydrologic processes with different set of SWAT parameters for different periods. For example, [16] used seasonal calibration scheme, in which winter and summer data were used to calibrate the model separately at two seasonally snow-covered watersheds in south-eastern Canada.

In the present study, hydrological analysis is carried out for different seasons i.e., Monsoon months and non-monsoon months as well as by considering data only for flood years, moderate years and drought years. Objective is to compare the results of these models to understand precise response of the basin in different set of calibration data and to determine if a particular approach is better suited to estimate high flood runoff through the basin.

3.1. Basin delineation, data used and development of LULC Map

For the assessment of West Banas River basin, delineation of drainage network carried out using SRTM data. Digital Elevation Model (DEM) of 30m resolution downloaded from USGS site. The ArcSWAT watershed delineator was used to delineate the watershed into sub watersheds, slopes, drainage areas, and drainage network using the DEMs. The entire West Banas River basin has been subdivided into 23 sub- basins.

The digital soil map (1:500,000) of India has been obtained from FAO SWAT database which was further extracted by mask for the basin. Land cover is the observed physical cover on the earth's surface [17]. Land use and land cover map was developed using freely downloaded remote sensing data and is shown in Fig. 2(ii). Six categories of land use were identified for this basin: Agriculture, forest, shrub land, barren, waters and urban, with the % area are tabulated in Table-1.

Rainfall data were collected from Indian Meteorological Department (IMD) and Water Resource department of Rajasthan from 1987 to 2018. Rainfall, gauge, discharge, cross section and sediment data were obtained from Centre Water Commission (CWC). Temperature, relative humidity, solar radiation, and wind speed data were taken from CFSR (Climate Forecast System Reanalysis) for the same period.

Table 1: Land use and land classification of year 2000

Land use/Landcover	Area in km^2	% Area
Agriculture	2761.0	55.6
Barren	367.3	7.4
Forest	424.7	8.5
Scrubland	1348.8	27.1
Urban	48.4	1.0
Water bodies	18.8	0.4

3.2. SWAT model development

Soil and Water Assessment Tool (SWAT) may be considered as one of the most representative distributed river basin hydrological model, [18, 19, 20] with various applications for hydrologic process. SWAT simulates surface runoff in a watershed by considering a variety of physical processes, including evaporation, runoff, infiltration processes, potential and actual evapotranspiration, lateral runoff, and groundwater contributions. In SWAT model development sub-watersheds are delineated using input DEM. After providing LULC, soil, and slope maps, sub-watershed are divided into several homogenous units called hydrologic response units (HRUs) having unique soil, slope and land use classes. After specifying time step as monthly, simulation period of 32 years, and warmup period of 2 years, water balance diagram is generated and analyzed. The results of each sub basin data could be extracted and analyzed manually through SWAT output files.

3.3. SWAT model Calibration

Using the collected and processed data different calibrated and validated SWAT models were developed using daily stream flow data at Sarotry gauge station of the basin. The model performance statistics were evaluated and the availability of water within the catchment also assessed based on the water balance ratios. The SWAT model includes a large number of soil, groundwater and other parameters which describe the different hydrological conditions and characteristics across the basin [21]. Both manual and automated calibrations were performed to adjust the parameters to match the observed information. Multiple iterations of the SUFI-2 algorithm performed automatic calibration with SWAT-CUP to readjust the parameters to better match the observed values and further manual calibration is performed to optimize the different water balance components such as streamflow, baseflow, return flow. Initial ranges were decided based on absolute range and geographical properties of the basin. The calibrated parameters and their ranges are shown in Table-2 for the model named as SAS (SWAT All Season) model.

Table 2: SWAT CUP Parameter definition as optimized.

Parameter	Description	Range selected	Final Optimal value
CN2	Curve number for soil water condition.	35 to 98	42.1
ALPHA_BF	Base flow alpha factor (days).	0 to 1	0.622
GW_DELAY	It is lag time between time that water exit the soil zone and then enter the shallow aquifer.	0 to 500	20.35
SOL_AWC	Available water capacity of the soil layer	0 to 1	0.153
SOL_K	It defines how much easily the of water moves through the soil. (Hydraulic conductivity).	0 to 2000	11.937
GW_REVAP	It defines how much the water from shallow aquifer transfers to root zone.	0.02 to 0.2	0.317

REVAPMN	It is threshold water depth in shallow aquifer so that percolation to the deep aquifer can be occurred.	0 to 500	231.39
GWQMN	It is threshold water depth in shallow aquifer so that return flow will occur.	0 to 5000	2000
RCHRG_DP	Deep aquifer percolation fraction	0 to 1	0.405

3.4. Swat model Calibration for seasonal variations

It was anticipated that a separate calibration method would be an effective way to cope with the SWAT calibration issue for the basin where a distinct difference of runoff fluxes exists for different periods within a year to account for the inevitable contrast between performance of dry and wet periods. This was also illustrated in a published study in which the seasonal calibration method was used to calibrate a concept model [22]. This study focuses on improving the SWAT model by extending the original SWAT (version 2009) with the seasonal calibration scheme, namely SWAT-SC, which calibrates and simulates the dry and wet periods separately.

The average rainfall for different months of a year in West Banas basin shows that among all the months, only monsoon months (June, July, August & September) has major contribution to the discharge. As analysis is done to obtain discharge against rainfall and a separate analysis carried out for the monsoon and non-monsoon months, it was observed that when the simulated discharge values compared with respect to the observed discharge values, a different pattern is observed for the monsoon months. Therefore, SWAT model were calibrated for different set of data i.e., for monsoon months and non-monsoon months. These different models so developed were named as SM (Swat Monsoon) and SNM (Swat Non-Monsoon) models.

The SWAT model were also calibrated using data of flood years, moderate years and drought years only. Those years having average annual rainfall more than 900 mm were grouped in flood years and those having rainfall less than 500 mm were grouped in drought years while moderate flood years having annual rainfall between 500 mm to 900 mm. Model so developed named as SFY (SWAT Flood Year), SMY (SWAT Moderate flood Year) and SDY (SWAT Drought Year). These are tabulated for convenience in Table-3.

Table 3: Nomenclature of various SWAT models used in the study.

Model	**Description of developed SWAT model calibrated with different set of Data**
(i)	**Based on seasonal calibration for wet and dry months of the year.**
SAS	Model calibrated for all months of all years (all seasons)
SM	Model calibrated for monsoon months for 32 years
SNM	Model calibrated for non-monsoon months for 32 years
(ii)	**Based on calibration for flood, moderate and drought years.**
SFY	Model calibrated for flood years (years of rainfall > 900 mm)
SMY	Model calibrated for moderate years (years of rainfall between 500 to 900 mm)
SDY	Model calibrated for drought years (years of rainfall < 500 mm)

4. Results and Discussions

4.1. SM and SNM model performance

SM and SNM model so developed are calibrated specific to the data of Monsoon months and non-monsoon months respectively. For the validation of these model, the simulated discharge obtained through SWAT model were also compared with the observed Discharge. The efficiency of these SWAT models is evaluated by 03 evaluation criteria (i) R^2 (coefficient of correlation) that indicates the extent of similarity in variation of different data, (ii) NSE (Nash Sutcliffe model Efficiency) which indicates the predictive power and accuracy of simulated discharge and (iii) PBias (Percentage Bias) which indicates deviation of runoff volume and indicates the goodness of fit. The R^2, NSE and PBias values for SAS, SM and SNM models are tabulated in Table-4 for comparison.

Table 4: Different Swat Model performance with seasonal variation.

Evaluation Parameter\Model	SAS	SM	SNM
R^2	0.76	0.75	0.27
NSE	0.58	0.64	-28.01
PBIAS	-103.7%	-31.5%	-1400%
Ratio of average simulated discharge to observed discharge	1.56	0.97	13.48

Performance indices values of the results obtained from SM model were R^2 as 0.75, NSE as 0.64 and PBias as -31.5% while these corresponding values for SAS model are 0.76, 0.58 and -103.7% respectively and corresponding values for SNM model are 0.27, -28.1 and -1400% respectively. By performance of these models, it can be fairly concluded that performance of swat model for average discharge enhanced considerably while calibrating the model for Monsoon months only and for non-monsoon months the model performance deteriorated considerably. To get a fair idea of the overall response of basin by the calibrated SWAT models, the ratio of average simulated discharge to the observed discharge was also calculated and it was observed that value of ratio for SM model is 0.97 while for SAS model it was 1.56 and for SNM model it was 13.48. These results strengthen that the research work done of calibrating the SWAT models for different periods, specifically for the monsoon months only, give very good results. This will help for proper basin management during floods as response of the basin for the peak rain fall events can be predicted in more logical way with better accuracy.

4.2. SFY, SMY and SDY model performance

Calibration of SFY, SMY and SDY models done using specific data of flood years, moderate flood years and drought years only. The efficiency of performance of these models is once again analyzed with the help of performance evaluation parameters viz. R^2, NSE and PBIAS. For the validation of these model, the simulated discharge obtained through SWAT model were also compared with the observed discharge. The R^2, NSE and PBias values for SFY, SMY and SDY models are tabulated in Table-5 for comparison.

Table 5: Different Swat Model performance for typical years Flood, Moderate and drought years.

Evaluation Parameter\Model	SFY	SMY	SDY
R^2	0.73	0.67	0.30
NSE	0.62	0.08	-1.14
PBIAS	-76.6%	-217.2%	-126.6%
Ratio of average simulated discharge to observed discharge	1.13	3.06	2.70

Performance indices values of the results obtained from SFY model were R^2 as 0.73, NSE as 0.62 and PBias as -76.6% while these corresponding values for SMY model are 0.67, 0.08 and -217.2% respectively and corresponding values for SDY model are 0.30, -1.14 and -126.6% respectively. Therefore, it can be fairly concluded that performance of swat model for flood years is better in comparison to the SMY and SDY. The ratio of average simulated discharge to the observed discharge was also calculated and it was observed that value of ratio was 1.13 for SFY and for SMY it is 3.06, which reinforces the findings that model for flood years (SFY) give better response to the basin.

5. Conclusions

The study was aimed to develop a SWAT based hydrological model to simulate the rainfall events in West Banas basin, a typical semiarid basin of India. Using available datasets of all seasons and after thorough calibration, the model satisfactorily represented the hydrological processes at basin scale at reasonable time scale of 32 years. Performance of the model was evaluated using various evaluation criteria and performance of simulated discharge as output from the developed model. Though the performance criterion fell in desirable range, however in order to evaluate possible improvement in the calibration, multiple models were developed based on using only the monsoon season or non-monsoon season data and also using data of years which could be classified as flood years, moderate years and drought years. Study indicated that calibration using only monsoon season data may be better suited to predict high flood runoff from the basin. This could be combined with predicted land use-landcover changes in the basin and predicted climate data to likely climate scenario, of the watershed to predict the changes in estimated flood runoff due to climate change with the developed models with seasonal calibration.

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