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Optimization of climate resilient water conservation strategies using swat under climate change situation

SK Upadhye, MU Kale, SM Taley and RN Katkar

Abstract
The water conservation strategies often called best management practices or BMPs are widely used as effective measures for water harvesting or runoff reduction from watershed. The lack of land use planning and the absence of conservation practices in a watershed can contribute to increased runoff. The objective of this study was to optimize the climate resilient water conservation strategies under climate change situation with special emphasis on the contribution of conservation practices in reducing average annual runoff from Manasgaon watershed located in Shegaon tehsil of Buldhana district.
The hydrological simulation was carried out by using Soil and Water Assessment Tool (SWAT) model, which was integrated with Arc GIS software, for one of the most important parameter of hydrology i.e., runoff. The SWAT-CUP SUFI-2 technique was used for sensitivity analysis, calibration and validation of the model. The model was calibrated using observed runoff data of watershed for ten years (1998-2007) and validated for another set of data for the period 2008-2014 (seven years) with three years data (1995 - 1997) for the warm up of the model.
The reasonably high Nash-Sutcliffe coefficient (NSE) values for the calibration and validation periods (0.81 and 0.76 respectively) indicated good performance of the model.
The strip cropping treatment was found more effective in reducing runoff followed by terracing. It has been also concluded that the scenario WCS-10 (i.e., conversion of barren land to fair pasture, strip cropping on agricultural land (0-2 %), contour farming (2-4 per cent slope), terracing (4-8 per cent slope) and farm ponds in all sub basins) is found more effective in reducing runoff followed by scenario WCS-6 (i.e., conversion of barren land to fair pasture, strip cropping on agricultural land and farm ponds in all sub basins). The combined effect of different treatments is more effective in reducing runoff than individual effect of each treatment. The calibrated and validated SWAT model can be effectively used for simulation and optimization of different water conservation strategies for Manasgaon watershed.

Keywords: SWAT, SUFI-2, optimization, water conservation, watershed, runoff

Introduction
Water supports all forms of life on this mother earth. It is an essential element for survival of living things. It is a key resource for sustainable agricultural, industrial, economic and social development. Water resources have become a critical element for socioeconomic development, especially in the arid and semi-arid regions. Because of the human activities (e.g., increasing global population (Pangare, 2006; Notter *et al.*, 2011) [32, 31], land-use change (Vörösmarty, 2010) [39], water pollution (Duan *et al.*, 2011; Duan *et al.*, 2013) [12, 13] and climate change, water resources are under severe pressure further triggering water scarcity issues and water shortages have become the major crises of sustainable development of communities all over the world. Identification and prioritization of critical erosion prone areas is an important consideration for policy makers for the effective and efficient implementation of best watershed management strategies (Tripathi *et al.*, 2003; Kumar and Mishra, 2015) [36, 21, 22].
To deal with water management issues, one must analyze and quantify the different elements of hydrologic processes taking place within the area of interest. Obviously, this analysis must be carried out on a watershed basis because all these processes are taking place within individual micro-watersheds. The objective of improving the productivity, profitability and prosperity of the agricultural sector on an ecologically sustainable basis can be attained only when conservation, development and management of the land and water resources are assured. Watershed is an ideal unit for carrying out scientific resources management for ensuring continuous benefit on sustainable basis. The water harvesting structures not only control the erosion but also conserve the water. Watershed prioritization is thus the ranking of different critical sub-basins of a watershed according to the order in which they have to be taken up for treatment and soil conservation measures (Tripathi *et al.*, 2003) [36].

Simulation models are mostly used to analyse the effect of management practices on water quality but they can also be a useful tool to quantify the hydrologic response of a catchment to different land use options (Schultz, 1993) [35]. Hydrologic models are symbolic or mathematical representation of known or assumed functions expressing the various components of a hydrologic cycle. (Reshma *et al.*, 2010) [3]. The term watershed modeling generally refers to the simulation of the processes that takes place in the watershed. (Hernandez *et al.*, 2000) [15].

Soil and Water Assessment Tool (SWAT) has been found as the most efficient model for simulating runoff, sediment yield and water quality in recent years. SWAT is a process based, distributed parameter, continuous time scale watershed model, capable of simulating long-term effects of management change. As a physically based model, SWAT uses hydrologic response units (HRUs) to describe spatial heterogeneity in land cover and soil types within a watershed. The model estimates relevant hydrologic components such as surface runoff, baseflow, evapotranspiration (ET) and soil moisture change for each HRU (Hua *et al.*, 2008 and Zhi *et al.*, 2009). Further it has been widely used since 1993 for issues related to watershed and hydrology (Arnold *et al.*, 1998; Behera and Panda, 2006; Kangsheng and Johnston, 2007 and Ashraf *et al.*, 2014) [6, 9, 19, 8, 19]. It is a hydrological model functioning on a time step of daily or monthly. In addition, it was used for evaluating the impact of climate change and anthropogenic factors on stream flow, agricultural chemical and sediment yields in large river basins (Arnold *et al.*, 1998) [6]. SWAT is developed for the watershed hydrological features, organization manipulation and storage of the related spatial and tabular data with an interface in ArcView GIS. The current study was undertaken on the application of the SWAT model which integrates the GIS information with attribute database derived from remote sensing and conventional measured climatic parameters to estimate the runoff.

Knowledge on how the local hydrologic cycle and water resources will be affected by soil-water conservation measures, land-use and climate changes is essential for designing reliable climate adaptation strategies and water policy. The regional impacts of land-use and climate change on hydrology vary from place to place, hence local scale studies should be conducted (Lai and Arniza, 2011; Mango *et al.*, 2011; Wang *et al.*, 2014) [23, 24, 40]. It is widely agreed that land use change and climate variability are two active environmental factors profoundly affecting watershed hydrology (Chen *et al*., 2012; Molina-Navarro *et al*., 2014; Wang *et al.*, 2014) [11, 25, 40]. However, such detailed assessments of local hydrology are still limited in Vidarbha region.

Under the changing climate scenario, rainfall variability resulting scarce water resources in Vidarbha in general and in proposed study area in particular, it is of prime importance to adopt suitable soil and water conservation strategies for harvesting maximum runoff. The findings of this study will provide a better understanding of hydrological impacts of soil and water conservation measures to assure better water resources management and effective reduction of the flood vulnerability, drought management towards sustainability practices in study area.

Considering hydrological behavior of the study watershed and applicability of the existing models, the current study Optimization of water conservation strategies was undertaken with the application of SWAT in integration with GIS and remote sensing to estimate the surface runoff for Manasgaon watershed located in Shegaon tehsil of Buldhana District, Maharashtra. The specific objective of the present study is to calibrate and validate the Arc-SWAT model for runoff estimation in Manasgaon watershed, to study the impact of different water conservation strategies on runoff and to suggest suitable water conservation strategies to harvest maximum runoff.

Material and Methods

Location and Climate

The study area selected was Manasgaon watershed located in Shegaon tehsil of Buldhana district. The study area is located in Sangrampur and Shegaon tehsil of Buldhana district and Akola and Telhara tehsil of Akola district in Vidarbha region of Maharashtra. The area comes under Survey of India toposheet number 55D9. The outlet of the watershed is at Manasgaon and located at latitude 20° 54' 45" N and longitude 76° 41' 27" E. Most of the area comes under saline tract of Purna river basin. The study area is located between 20°50' N to 20°58' N latitude and 76°42' E to 76°47' E longitude. The location map of Manasgaon watershed is depicted in Fig. 1. The region is classified as hot moist semi-arid climate with medium and deep clayey black soils (shallow loamy to clayey black soils as inclusion), medium to high AWC and LGP of 120-150 days. It receives an average (1995-2014) annual rainfall of 715.6 mm in 39 rainy days. The average rainfall during monsoon season (June to September) is 626 mm and ranges from 348 to 1055 mm. The major crops grown in the region are cotton, soybean, pigeonpea, green gram and black gram during *kharif* season and chickpea, safflower and sunflower during *rabi* season.

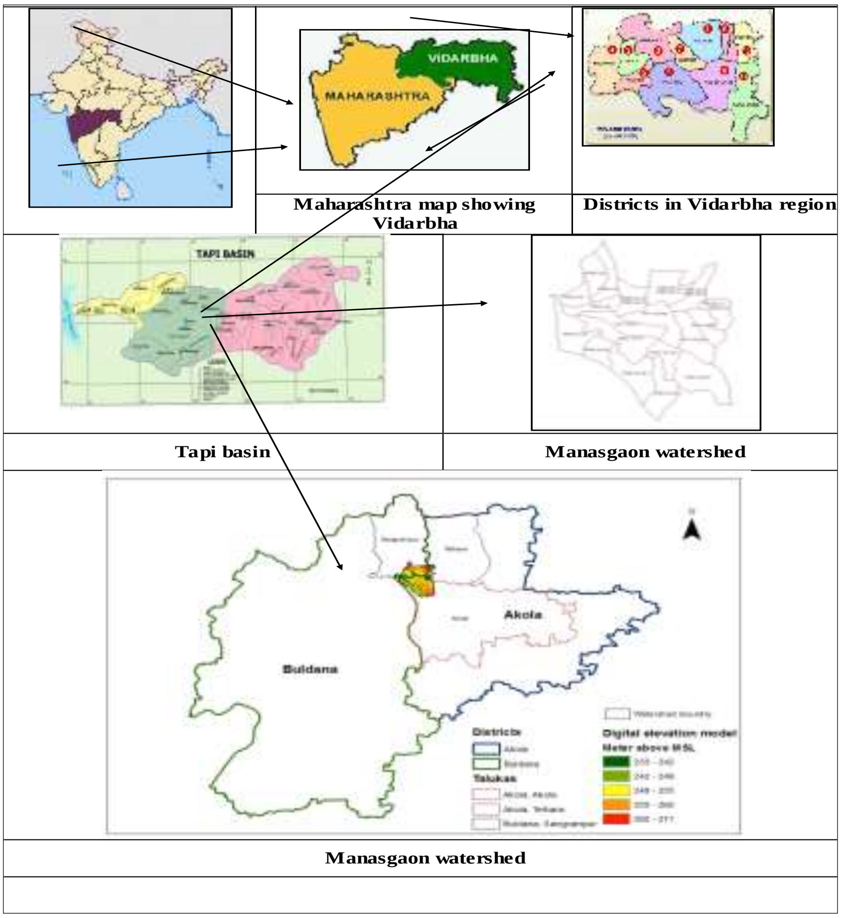

Fig 1: Location map of Manasgaon watershed

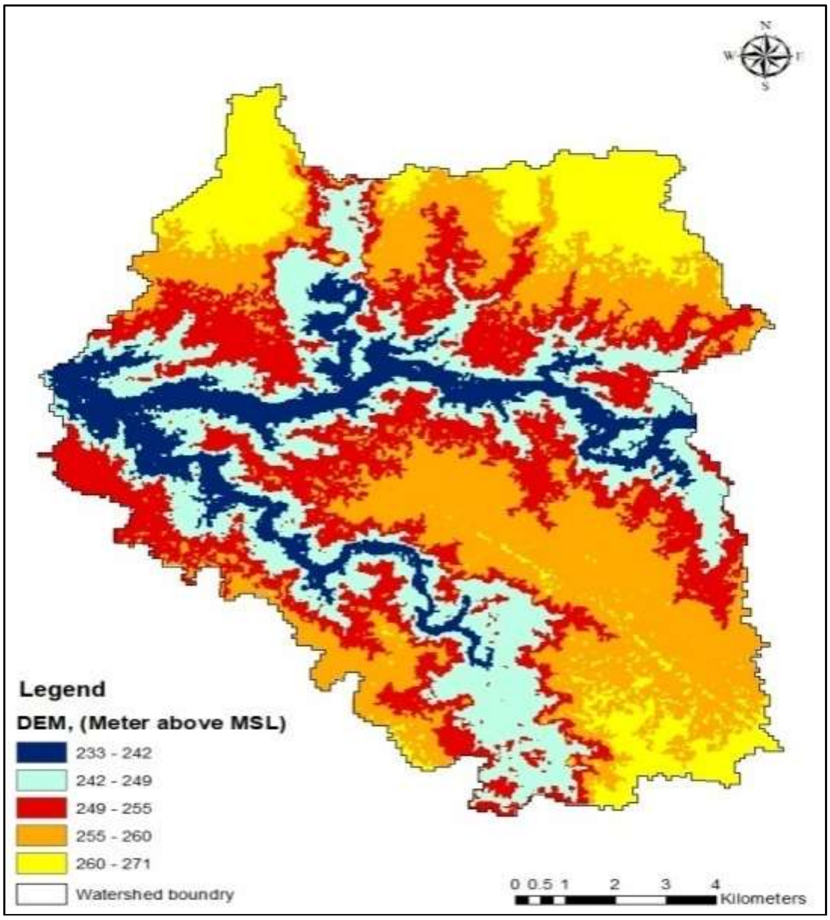

Fig 2: Digital Elevation Model of the study area

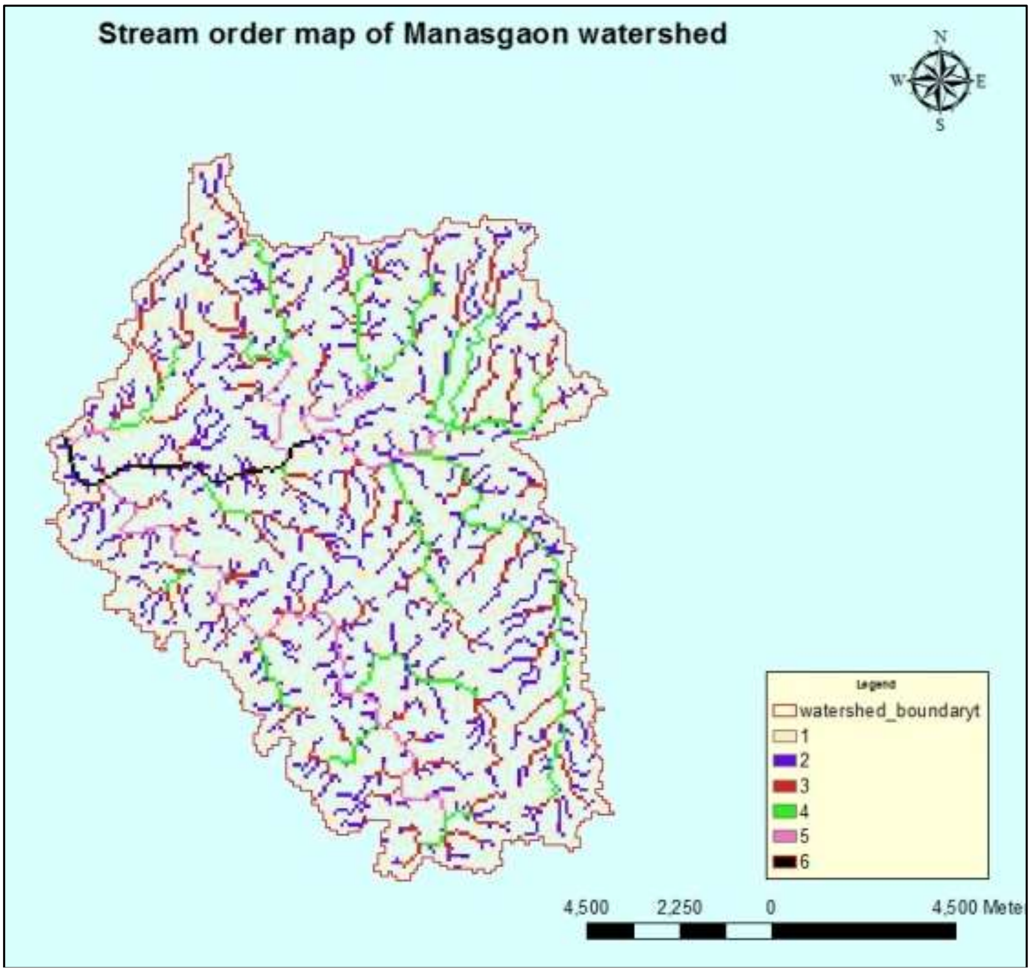

Fig 3: Stream order map of Manasgaon watershed

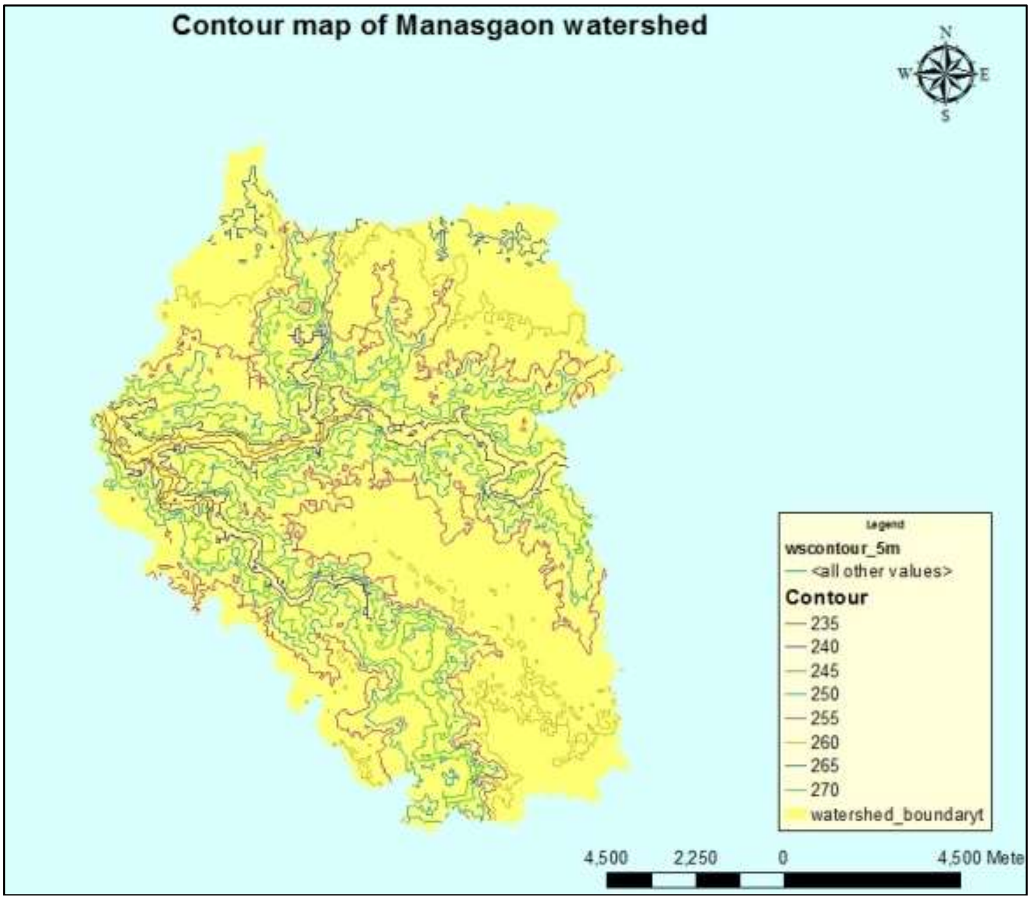

Fig 4: Contour map of the study area

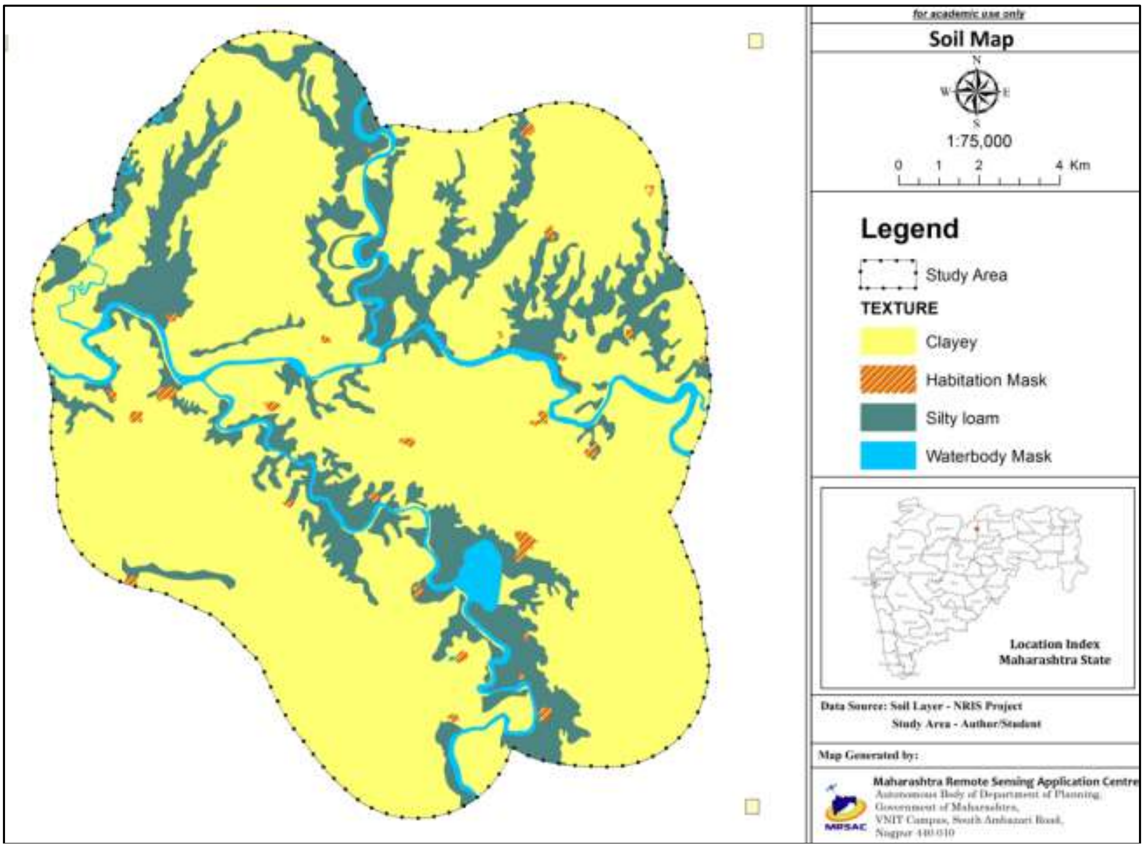

Fig 5: Soil map of the Manasgaon watershed (*Source*: MRSAC, Nagpur)

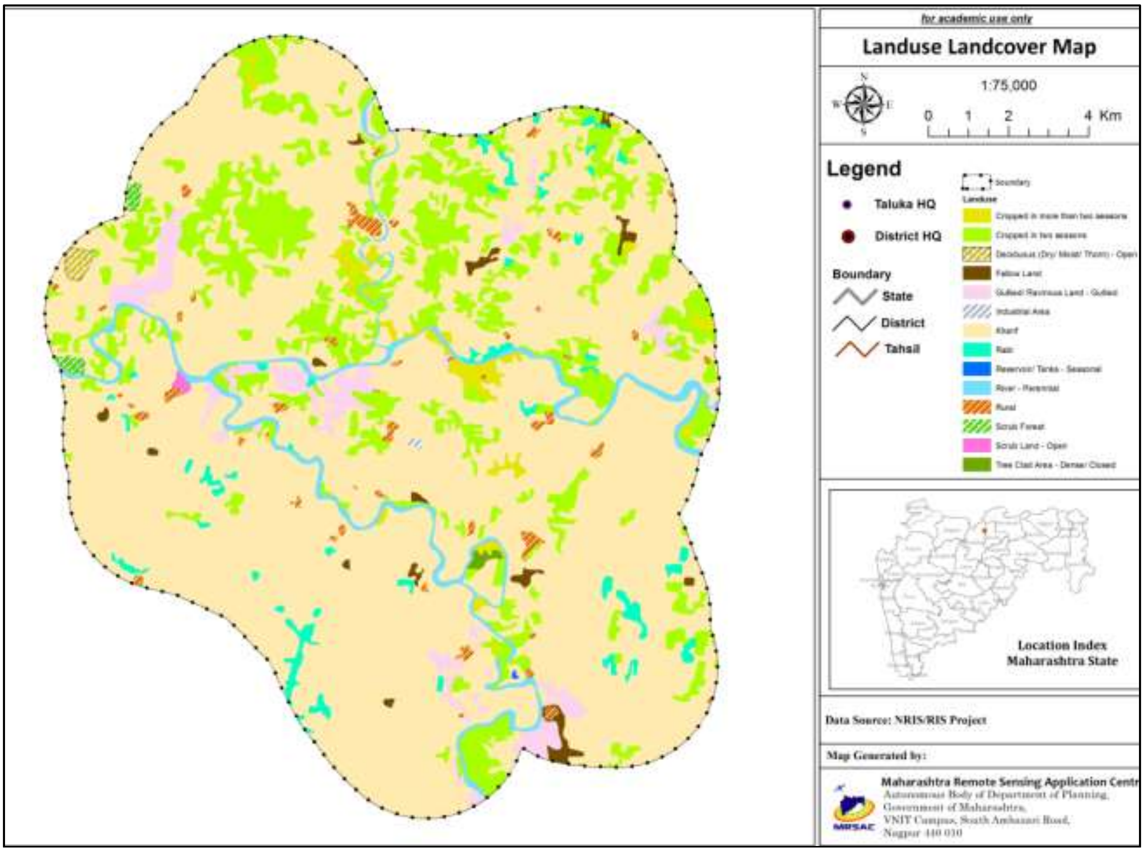

Fig 6: Land use/Land cover map of Manasgaon watershed (Source: MRSAC, Nagpur)

Data Collection and Pre-processing

For modeling studies, a large number of data is required which was collected from different sources. The collected data is then processed as per the model specifications.

The area under study comes under Survey of India Toposheet No. 55D9 and was obtained from Office of the Survey of India, Maharashtra and Goa Geo-Spatial Data Center, Pune. It was used for demarcation of the watershed boundaries.

The daily meteorological data of rainfall, maximum and minimum temperature, wind speed, relative humidity, sunshine hours and evaporation was obtained from the meteorological observatory installed at Manasgaon watershed. The gauge discharge data i.e., runoff was obtained from Water Resources Department, Nashik. The meteorological and hydrological data for the period 1995-2014 (20 years) was received from the Water Resources Department, Hydrology Project Circle, Hydrology Project (SW), Jal Vidnyan Bhawan, Nashik. The SWAT model requires input data in particular formats and units. Two files of each parameter, one containing the gauge location and second containing data were prepared in database format.

Description of input data for Arc SWAT

Spatial dataset

In the present study, SWAT 2012 interface of Arc GIS was used to meet the objectives of the study. The spatial data *viz.*, digital elevation model (DEM), soil map and land use / land cover map (LULC) of the study area has been used. The Digital Elevation Model (30m x 30m) of the study area (fig. 2) was downloaded from http://www.gdem.aster.ersdac.or.jp/. The DEM was used for determining the drainage network of the study area, watershed boundary, sub basins and slope map. The drainage network and contour map of the study area is shown in Fig. 3 and 4.

The details regarding the soils and soil series of study area was obtained from National Bureau of Soil Science and Land Use Planning (NBSS & LUP), Nagpur, Maharashtra State Remote Sensing Application Center (MRSAC), Nagpur and Department of Geology, Sant Gadge Baba Amravati University, Amravati. The soil map obtained from MRSAC Nagpur is given in Fig. 5. The study area comprises eight soil series (fig.8) *viz.*, Bhalewari, Chopda, Nardoda, Savalikhera, Alampur, Jambha, Dhamangao and Sirpur. There are only two textural classes observed in the study area *viz.*, clayey and silty loam. The majority of the soils in the study area are clayey in texture and deep to very deep.

The LULC map was obtained from Maharashtra Remote Sensing Application Center (MRSAC), Nagpur (Fig.6). The study area was divided in six land use / land cover classes *viz.*, (i) *Kharif*, (ii) Double crop, (iii) Gullied / Ravinous land, (iv) Wasteland, (v) *Rabi* and (vi) Water. The total area of the selected watershed was15197.22 ha. The major area of the watershed was under *kharif* cropping (65.03 per cent) followed by gullied / ravinous land (22.88 per cent), double cropping (6.01 per cent), wasteland (5.57 per cent), water (0.5 per cent) and *rabi* cropping (0.01 per cent). The spatial distribution of different land uses in Manasgaon watershed is shown in figure 7.

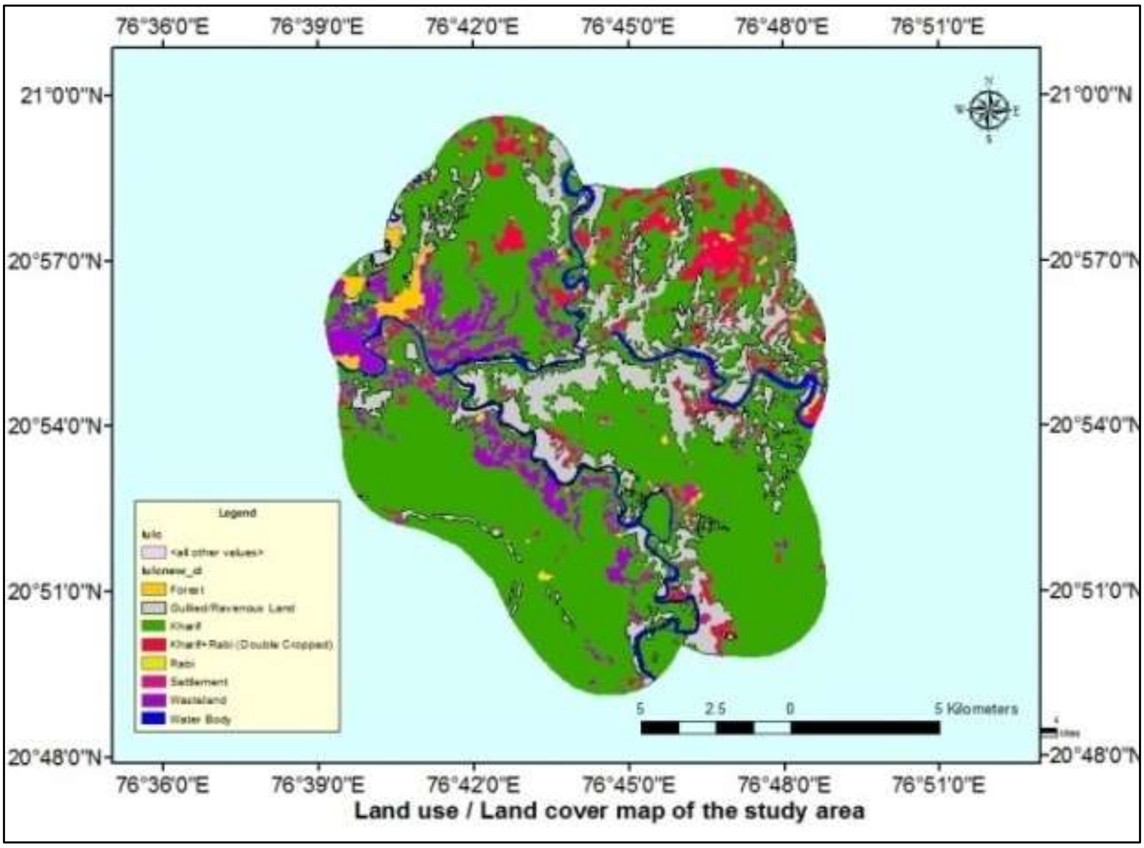

Fig 7: Land use/land cover map of the Manasgaon watershed

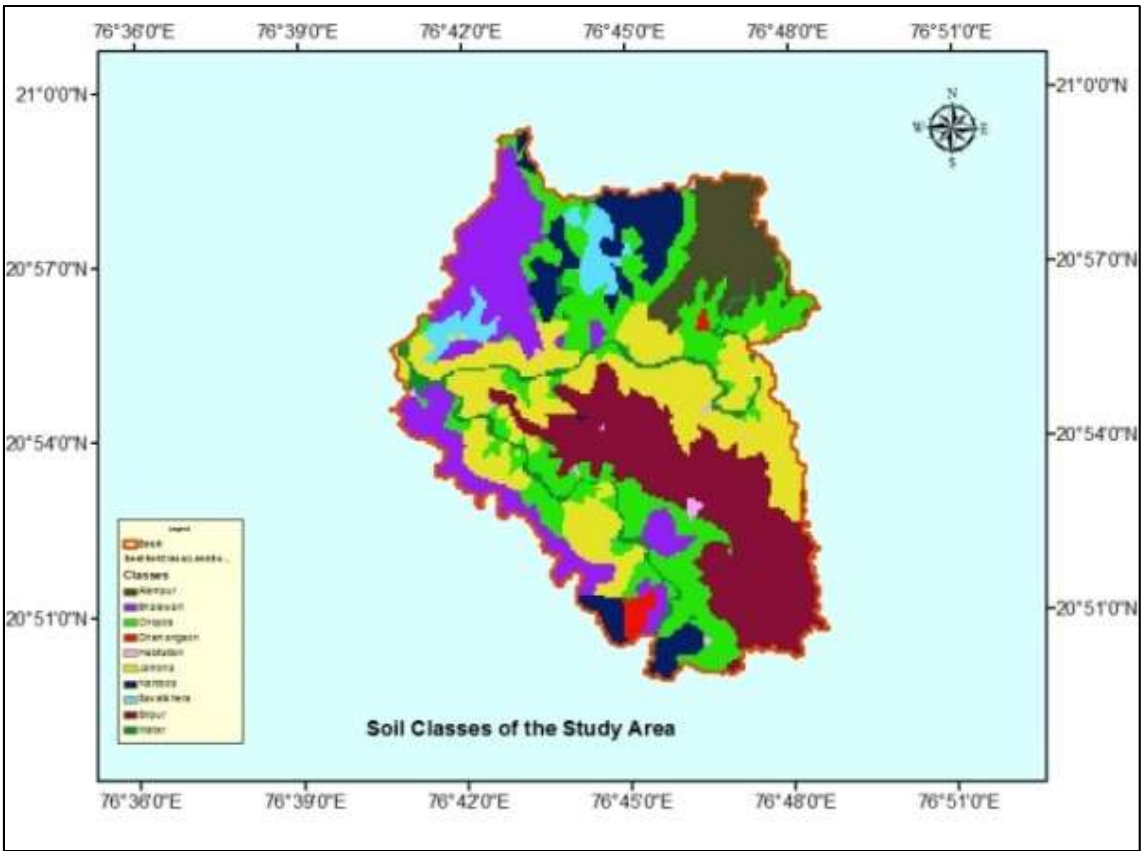

Fig 8: Soil series map of the Manasgaon watershed

Slope Map
The slope map of the study area was prepared from DEM and classified in four slope groups *viz.*, 0 - 2 per cent, 2 - 4 per cent, 4 - 8 per cent and > 8 per cent. The majority of the area comes under 0 - 2 per cent slope class (66.85 per cent) followed by 2-4 per cent slope class (25.83 per cent).

Softwares
The Arc SWAT - 2012, SWAT CUP SUFI-2, Arc GIS, ERDAS IMAGINE, MS Excel, Trendz, Weather Cock, etc. softwares were used for the analysis of the data.

SUFI-2 Algorithm of SWAT-CUP
The calibration and validation for the observed data was carried in SWAT-CUP 2012 model by using SUFI-2 method. It is capable of analyzing a large number of parameters and measured data from many gauging stations simultaneously (Narsimlu *et al.*, 2015) [27]. 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-CUP is specially developed by Abbaspour *et al.* (2007) [2] to interface with the SWAT model. Any calibration/uncertainty or sensitivity program can easily be linked to SWAT model by using this generic interface. In this study, the SUFI-2 algorithm was used to investigate sensitivity and uncertainty in streamflow prediction.
The hydrologic cycle as simulated by SWAT is based on the water balance equation (Neitsch *et al.*, 2005) [30]. Surface runoff or overland flow, is the flow that occurs along a sloping surface. Using daily or sub-daily rainfall amounts, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. Surface runoff volume can be computed either by using a modified SCS curve number method (USDA 7Soil Conservation Service, 1972) [37] or the Green and Ampt infiltration method (Green and Ampt, 1911) [14]. The SCS curve number method has been used in the present study.

Rainfall Trend Analysis
The daily rainfall data of previous 20 years period (1995-2014) recorded at Manasgaon gauging station were analyzed for trend analysis using Mann Kendall test and drought study using IMD criteria.

Model Calibration, Validation and Optimization
The flow chart depicting the steps in calibration, validation of the model and optimization of water conservation strategies is as shown in figure 9.
The watershed delineation includes five sections: DEM setup, stream definition, outlet and inlet definition, watershed outlet(s) selection and definition, and calculation of subwatershed parameters. The Sub-basin map along with stream network is shown in Fig 10. After watershed delineation, the subwatersheds are again divided into Hydrological response units (HRUs) with unique land use, soil and slope characteristics (fig.11).
Subdividing a watershed into areas having unique land use, soil and slope combinations, makes it possible to study the difference in evapotranspiration and other hydrologic conditions for different land use / land cover, soil and slopes. The three maps i.e. Land use map, Slope map and Soil map were then overlaid to create HRUs with unique land cover, soil and slope class. Hence, the whole watershed was divided into 25 sub basins and 197 number of HRUs.

Input files
All the input files *viz.*, soil data (.sol), weather generator data (.wgn), HRU general data (.hru), subwatershed data (.sub), main channel data (.rte), groundwater data (.gw), water use data (.wus), management data (.mgt), soil chemical data

(.chm), pond data (.pnd) and stream water quality data (.swq) were entered as per availability of data using the 'write all' command. A default Manning's 'n' value of 0.014 was used. Hargreaves Method was selected for computation of ET because of availability of daily temperature data. Curve number method was selected for calculation of runoff. Kannan *et al.* (2007) [20] also reported that the combination of CN method with Hargreaves ET estimation method gives good results than any other combination.

Swat Run

Model Setup and Preliminary Run

After loading all the input data and generating the required database files, SWAT is simulated for the period of 1995 to 2014, and calibration is performed for the period of 1998 to 2007 (10 years). Simulation from 1995 to 1997 was considered as a warm-up period to reduce the initial condition impacts, whereas the simulation from 2008 to 2014 (7 years) was used for validation. The model was run for monthly and yearly time step.

After successful running of the model, the output of the model were read with SWAT OUTPUT menu. The output for different HRU and sub basin were imported in database file format (.mdb). The hydrology or average water balance components of the watershed can be viewed by selecting SWAT RUN. After every simulation, it can be saved by giving suitable name.

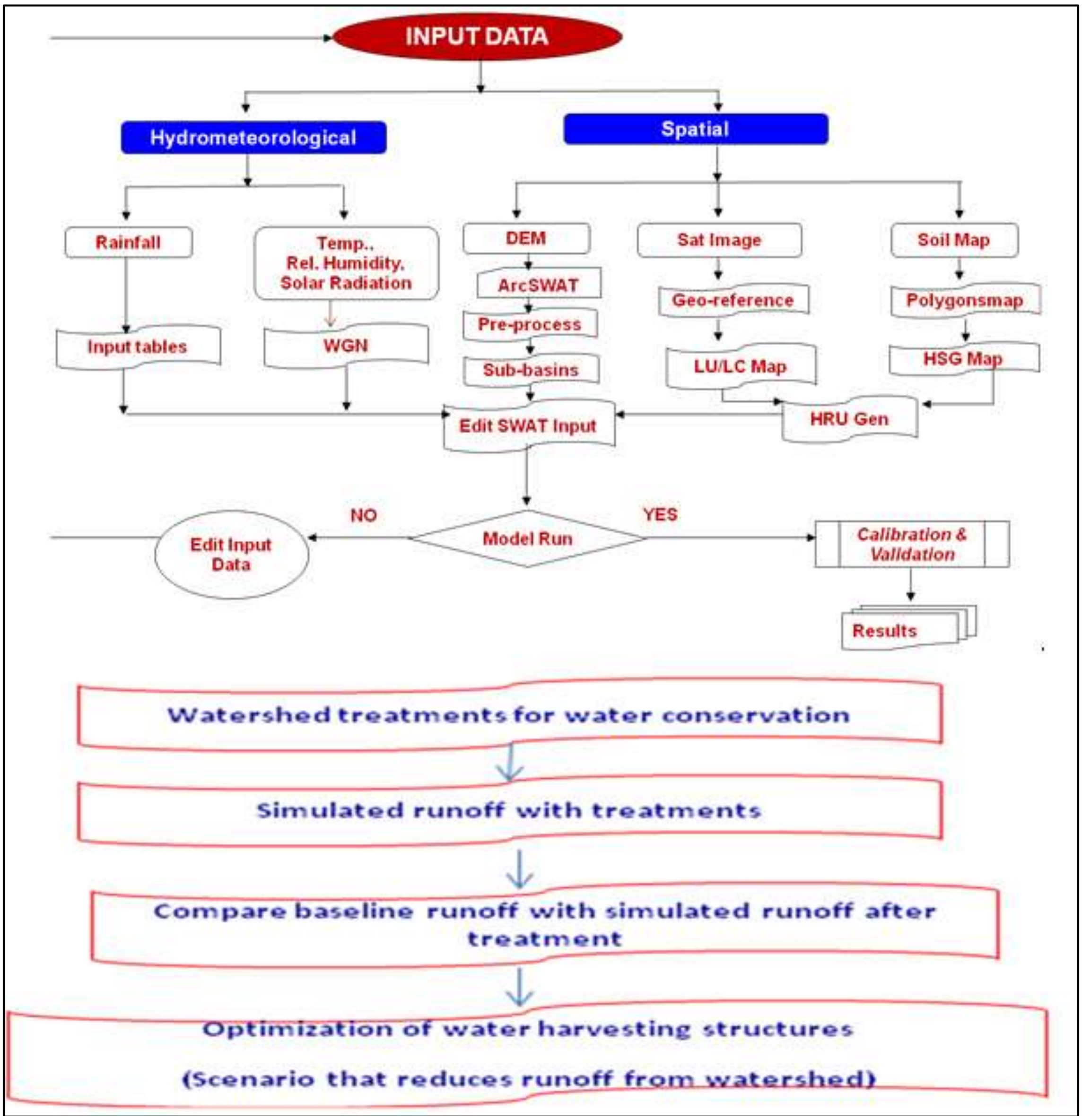

Fig 9: Flow chart for calibration and validation of the model

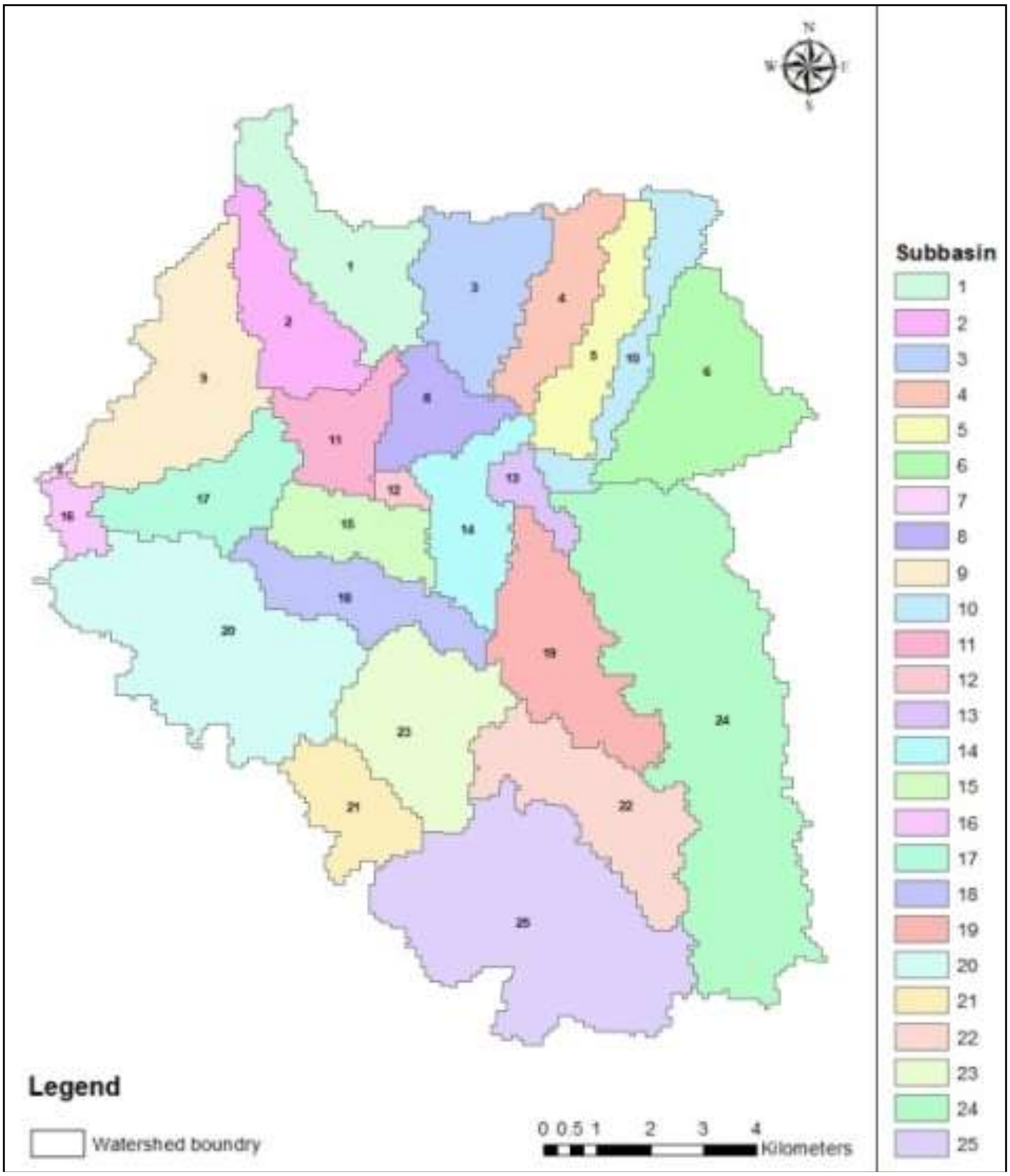

Fig. 10: Sub basin map of the Manasgaon watershed.

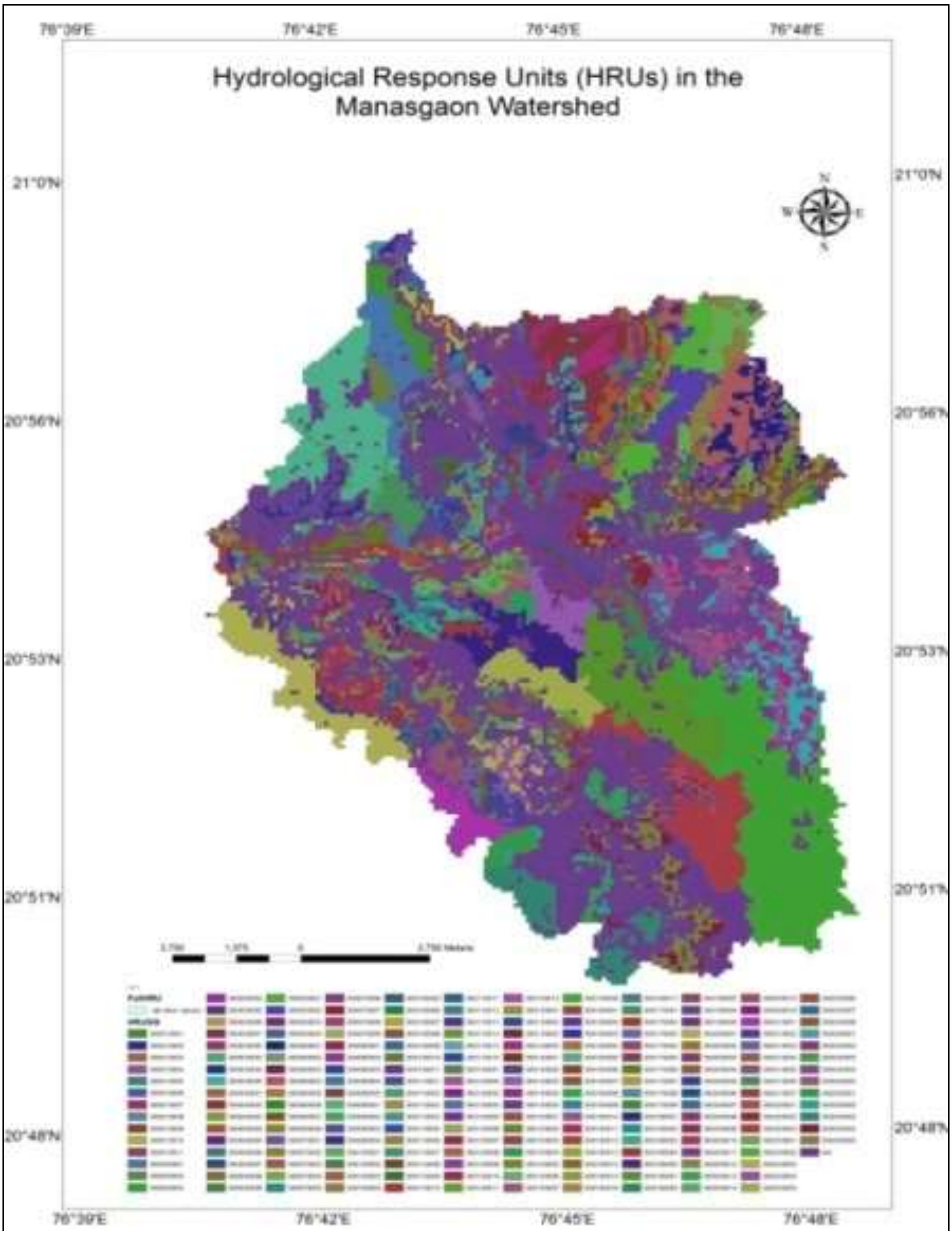

Fig 11: HRU map of the Manasgaon watershed.

Sensitivity analysis, calibration and validation of SWAT model

Physically based distributed models should be calibrated before they are made use of in the simulation of hydrologic processes to get a good match between observed and predicted flow values. Thus, to ensure efficient calibration, an appropriate sensitivity analysis has to be carried out. Sensitivity analysis establishes the relative importance of different parameters to the model output. Sensitivity analysis is the prerequisite for model calibration, which can help in pruning the number of parameters to be optimized during the calibration procedure.

Validation is the process to check whether the set parameter values in the calibration are good relation between the observed and predicted runoff data.

In present study, the sensitivity analysis, calibration and validation of SWAT model for stream flow was carried out using the open source software namely, SWAT Calibration and Uncertainty Program (SWAT-CUP) with Sequential Uncertainty Fitting (SUFI-2) technique which is an interface that was developed for SWAT. The SUFI2 method was chosen since, this method is faster, robust and versatile and also it can supply the widest marginal parameter uncertainty intervals of model parameters among the five approaches (Yang *et al*., 2008) [42].

A set of model parameters for sensitivity analysis have been selected by referring the relevant literature and SWAT documentation (Neitsch *et al.*, 2002) [29]. 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).

The list of sixteen parameters considered for global sensitivity analysis of stream flow, their location in SWAT model, description of the parameters are given in Table 3. The upper and lower bound parameter values were taken from the SWAT user manual (Neitsch *et al.*, 2005) [30]. Under SUFI 2, the global sensitivity analysis was considered and analysis was performed and the parameters were finalized based on their ranking of the parameters.

Model Evaluation

How well a model fits the observed data usually is determined by comparing model simulated or predicted values with the observed values. American Society of Civil Engineers (ASCE, 1993) [7] Task Committee on criteria for evaluation of watershed management models recommended that both visual and statistical comparisons between model-computed and measured quantities be made whenever data are presented. In the present study, Nash–Sutcliffe coefficient (Nash and Sutcliffe, 1970; Moriasi *et al.*, 2007) [28, 26], Coefficient of determination (Santhi *et al.*, 2001) [34], PBIAS, RSR were determined to check the performance of SWAT model.

Climate Resilient Water Conservation Strategies for reducing runoff or harvesting runoff

SWAT can incorporate different structural and non-structural Best Management Practices (BMPs) simultaneously, and simulate the watershed response. The average annual runoff from different sub basins will be sorted from maximum to minimum runoff. Considering the land use land cover, soil type and slope of the sub basins the different soil and water conservation measures will be suggested also known as Best Management Practices (BMPs).

The land use changes and water conservation measures *viz.*, conversion of barren land to pastures, contour farming, strip cropping, terraces / parallel terraces, detention pond, grassed waterway, filter strip, grade stabilization structure, stone bunds have been proposed to study the effects of individual water conservation measure or land use change on the runoff of the Manasgaon watershed.

All BMPs evaluated in this study were simulated by straight forward parameter changes in each of the calibrated input models. The impact analysis was carried out by comparing the scenario simulations with the respective baseline scenario (BASE); i.e., the calibrated model without any BMP implementation.

The different water conservation treatments considered based on land use land cover, soil type and slope of the watershed were Conversion of barren land to fair pasture (naturally growing grasses), Contour Farming on agricultural land, strip cropping of agricultural land, terracing and farm pond. The effect of individual treatment was studied by modifying the SCS CN II and USLE_P factor as suggested by Wischmeier and Smith, (1978) [41] and Arabi *et al.* (2004 and 2008) [4, 5]. The modification of these values were made in .mgt file of the SWAT model. The parameters in *.pnd file representing pond were modified as given in SWAT 2002 users manual (Neitsch *et al.*, 2002) [29].

Effectiveness of water conservation practices

The effectiveness of conservation practices implemented within agricultural fields or watershed were evaluated by comparing model simulations with no practice and simulations with the practice. Effectiveness of each practice (r) was computed as (Arabi *et al.*, 2008) [5].

$$r = \frac{(y_1 - y_2)}{y_1} \text{ x } 100 \qquad (1)$$

where, y_1 and y_2 reflect model outputs before and after implementation of the practice respectively.

Optimization of water conservation strategies

The impact of different water conservation strategies were tested for their effectiveness in reducing runoff or harvesting water. The different combinations considered are listed in Table 5 and abbreviated as scenario WCS (Water Conservation Strategy).

The simulated average annual runoff for the different scenario was compared with the baseline average annual runoff. The effectiveness of the scenario in reducing runoff (i.e., per cent reduction in runoff over the baseline runoff) was calculated. The optimization of different water harvesting strategies i.e., runoff reducing measures was carried out by simulating the combination of different strategies through SWAT model and found out the scenario giving maximum reduction in per cent average annual runoff over the baseline runoff.

Results and Discussion

Trend analysis of rainfall data

The rainfall variability described with the parameters *viz.*, mean, standard deviation, coefficient of variation, trend analysis using non parametric Mann Kendall test, probability of occurrence of rainfall and drought analysis. The average annual rainfall of Manasgaon watershed from 20 years (1995-2014) data is 715.6 mm. The maximum rainfall was observed in the year 2013 (1206.2 mm) and minimum rainfall was observed in the year 1999 (446.2 mm).

The trend analysis was carried out by using Mann-Kendall Test Statistic. There was no trend observed in the annual rainfall data of the Manasgaon watershed i.e., there was neither increasing nor decreasing trend in the annual rainfall data.

From table 1, it is observed that there is increasing trend in rainfall during July and there was no trend in rest of the months. The negative value of Z during June, August and October indicates decreasing trend whereas the positive value of Z during September indicates increasing trend even though it is not statistically significant. (fig. 12 to fig. 17).

Table 1: Monthly trend of rainfall at Manasgaon (1995-2014)

Month	S	Z	Normsdist	Trend
Jan	0.00	-0.03	0.51	No Trend
Feb	13.00	0.39	0.65	No Trend
Mar	16.00	0.49	0.69	No Trend
Apr	-11.00	-0.39	0.65	No Trend
May	-1.00	-0.06	0.53	No Trend
Jun	-32.00	-1.07	0.86	No Trend
Jul	56.00	1.78	0.96	Increasing
Aug	0.00	-0.03	0.51	No Trend
Sep	34.00	1.07	0.86	No Trend
Oct	-36.00	-1.20	0.89	No Trend
Nov	-7.00	-0.26	0.60	No Trend
Dec	5.00	0.13	0.55	No Trend

Drought Analysis of Manasgaon Watershed

The twenty years rainfall data (1995-2014) of Manasgaon watershed was analyzed for drought assessment using the criteria given by Indian Meteorological Department (IMD). The results are depicted in table 2. It is observed that, out of 20 years, seven years (35 per cent) were mild drought and four years (20 per cent) were moderate drought years and nine years were no drought years. Hence, out of twenty years, 55 per cent years have faced drought condition either mild or moderate. In other words it can be said that every alternate year may be drought year. Hence, it has become prime importance to adopt climate resilient water conservation measures for sustainable production.

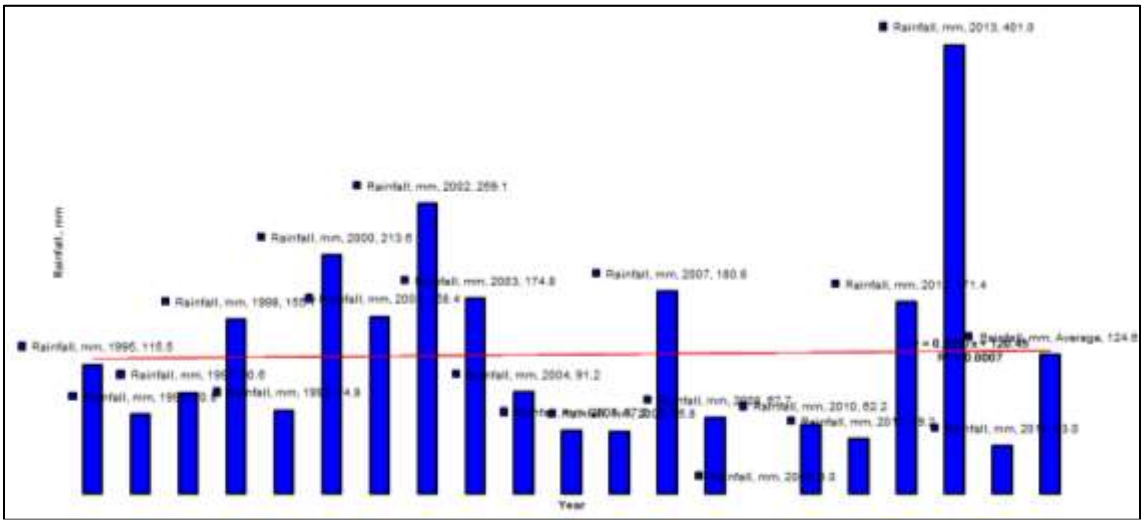

Fig 12: Rainfall pattern of Manasgaon watershed for the month of June (1995-2014)

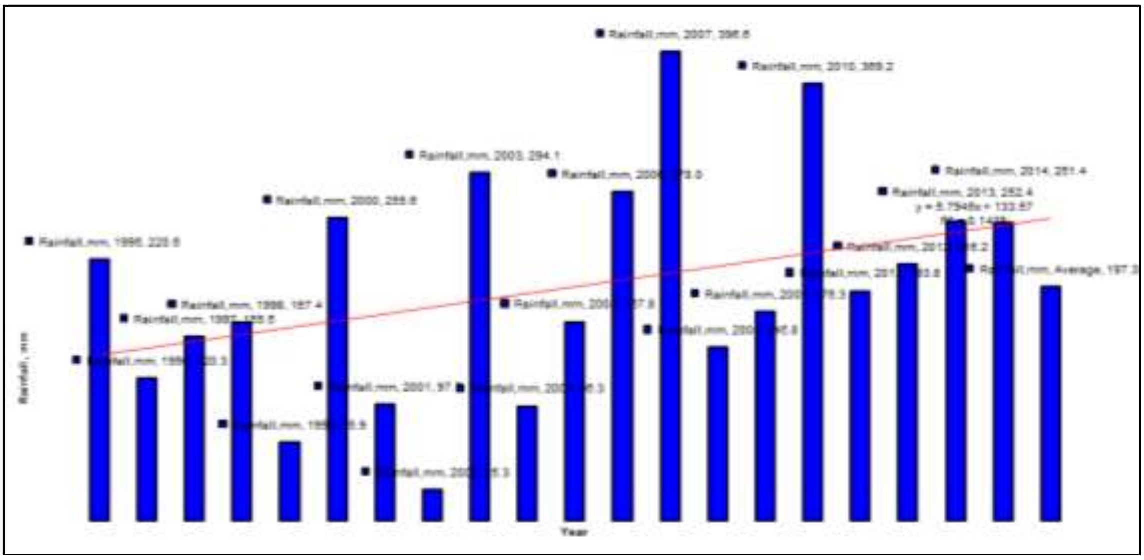

Fig 13: Rainfall pattern of Manasgaon watershed for the month of July (1995-2014)

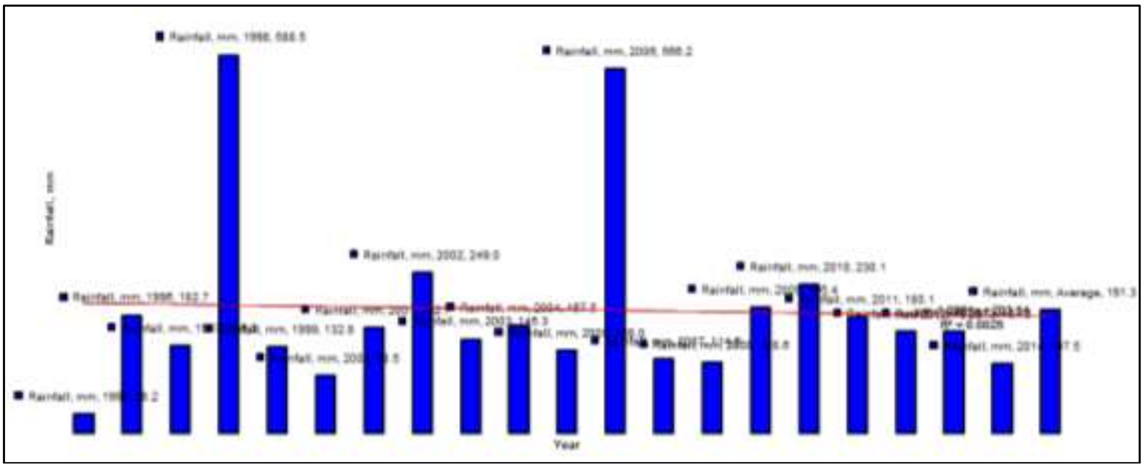

Fig 14: Rainfall pattern of Manasgaon watershed for the month of August (1995-2014)

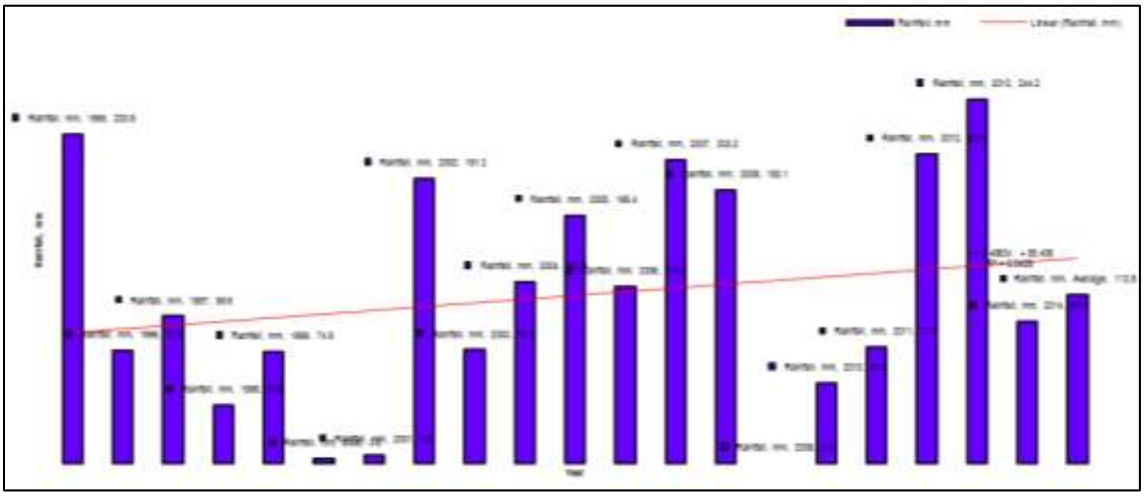

Fig 15: Rainfall pattern of Manasgaon watershed for the month of September (1995-2014)

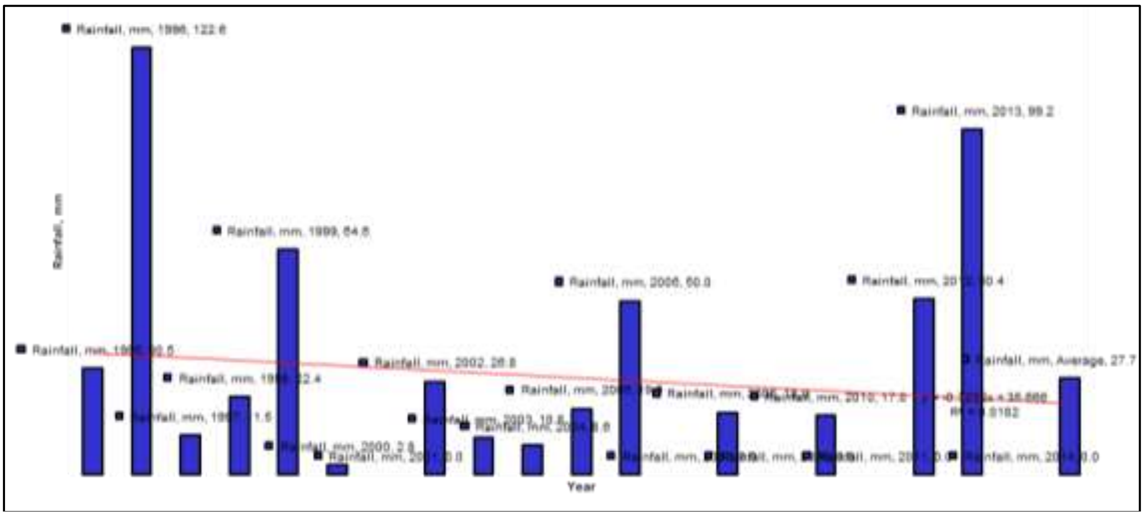

Fig 16: Rainfall pattern of Manasgaon watershed for the month of October (1995-2014)

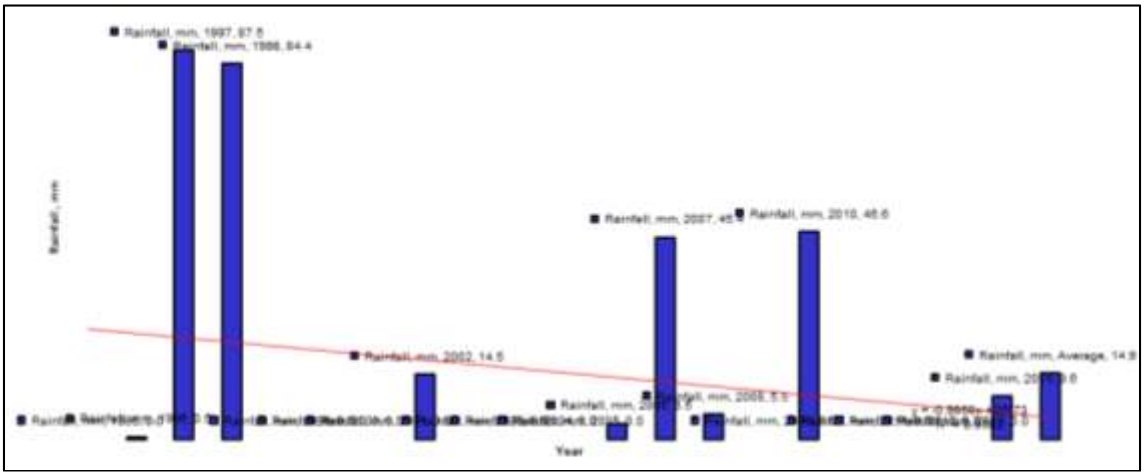

Fig 17: Rainfall pattern of Manasgaon watershed for the month of November (1995-2014)

Table 2: Drought analysis of Manasgaon watershed**.**

Sr. No.	Year	Rainfall, mm	Deviation (per cent)	Drought condition
1	1995	672.1	-6.08	Mild Drought
2	1996	873.6	22.08	No Drought
3	1997	610.5	-14.69	Mild Drought
4	1998	1059.0	47.99	No Drought
5	1999	446.2	-37.65	Moderate Drought
6	2000	580.1	-18.94	Mild Drought
7	2001	458.8	-35.89	Moderate Drought
8	2002	787.3	10.02	No Drought
9	2003	742.7	3.79	No Drought
10	2004	556.1	-22.29	Mild Drought
11	2005	569.2	-20.46	Mild Drought
12	2006	1071.7	49.76	No Drought
13	2007	953.4	33.23	No Drought
14	2008	562.7	-21.37	Mild Drought
15	2009	371.7	-48.06	Moderate Drought
16	2010	832.1	16.28	No Drought
17	2011	527.8	-26.25	Moderate Drought
18	2012	813.8	13.72	No Drought
19	2013	1206.2	68.56	No Drought
20	2014	617.2	-13.75	Mild Drought
	Average =	**715.6**		

Sensitivity analysis, calibration and validation of SWAT model

Sensitivity analysis

Sensitivity analysis and preliminary model trials were developed to identify the most influential parameters, which were adjusted during the calibration. Calibration and validation was performed through SUFI-2 technique of SWAT-CUP (SWAT Calibration Uncertainty Procedures, Abbaspour, 2012) [3]. Global sensitivity analysis method (Abbas *et al.*, 2016) [1] was used for finding the sensitive hydrological parameters responsible for streamflow in the Manasgaon watershed.

The parameters considered for sensitivity analysis are given in table 3. The upper and lower bound parameter values were taken from the SWAT user manual (Neitsch *et al*., 2005) [30]. Based on t-stat and p-value (table 4.14) it was observed that, CN2 (Initial SCS CN II value) was more sensitive followed by ALPHA_BF (Base flow alpha factor (days)) for Manasgaon watershed.

Table 3: Ranking of the parameters based on t-stat and P-value.

Sr. No.	Parameter Name	Description	Rank	t-Stat	P-Value
1	R__CN2.mgt	Initial SCS CN II value	1	17.815	0.000
2	V__ALPHA_BF.gw	Base flow alpha factor (days)	2	1.271	0.213
3	V__GW_DELAY.gw	Groundwater delay (days)	3	-0.589	0.560
4	V__GWQMN.gw	Threshold water depth in the shallow aquifer for flow(mm)	4	0.926	0.361
5	V__GW_REVAP.gw	Groundwater “revap” coefficient	5	0.927	0.360
6	V__REVAPMN.gw	Threshold water depth in the shallow aquifer for “revap” (mm)	6	-1.125	0.269
7	V__ESCO.hru	Soil evaporation compensation factor	7	0.150	0.882
8	V__CH_N2.rte	Manning’s n value for main channel	8	-0.461	0.648
9	V__CH_K2.rte	Channel effective hydraulic conduc-tivity (mm/hr)	9	0.624	0.537
10	V__ALPHA_BNK.rte	Baseflow alpha factor for bank storage (days)	10	0.859	0.396
11	R__SOL_AWC(..).sol	Available water capacity (mm H_2O/ mm soil)	11	-0.516	0.609
12	R__SOL_K(..).sol	Saturated hydraulic conductivity(mm/hr)	12	-1.018	0.316
13	R__SOL_BD(..).sol	Bulk density of soil	13	-0.173	0.864
14	R__HRU_SLP.hru	Average slope steepness (m/m)	14	0.033	0.974
15	R__OV_N.hru	Manning's n value for overland flow	15	-1.579	0.124
16	R__SLSUBBSN.hru	Average slope length (m)	16	-2.373	0.024

(R = multiplies the existing value with (1 + the given value) ; V = replaces the existing value with the given value)

Model performance for calibration and validation

The monthly observed and simulated flow values for the calibration period (1998 - 2007) and validation period (2008 - 2014) are plotted shown in Fig. 18-19 and Fig. 20-21 respectively. The model performance was evaluated using the statistical indices namely, Nash Sutcliffe efficiency, Coefficient of determination, PBIAS and RSR.

Nash Sutcliff was selected as goal type with behavioral threshold as 0.50. The number of simulations were carried as 50.

During the calibration and validation of SWAT model for Manasgaon watershed, Nash Sutcliffe Efficiency (NSE) was observed as 0.81 and 0.76 respectively. Santhi *et al.* (2001) [34]; adapted by Bracmort *et al.* (2006) [10] reported NSE greater than 0.50 is satisfactory for calibration and validation of SWAT model. This indicates that the performance rating of the calibrated and validated SWAT model for Manasgaon watershed was very good.

The Coefficient of determination (R^2) value for the calibration and validation obtained was 0.94 and 0.77 respectively. The model performance was considered acceptable or satisfactory when the R^2 is greater than 0.6. (Santhi *et al*., 2001; Kang *et al*., 2006) [34, 18]. Hence, the performance of the calibrated and validated SWAT model for Manasgaon watershed was considered as satisfactory.

The Percent bias (PBIAS) value for the calibration and validation obtained was 17.4 and 7.1 respectively. The model performance was considered satisfactory when PBIAS is < 10 per cent to < 25per cent. (Van Liew *et al.,* 2007) [38]. Hence, the performance of the calibrated and validated SWAT model for Manasgaon watershed was considered as satisfactory.

The Root mean square error observation standard deviation ratio (RSR) value for the calibration and validation obtained was 0.44 and 0.49 respectively. The model performance was considered very good when RSR is 0.00 ≤ RSR ≤0.50 (Moriasi *et al.,* 2007) [28]. Hence, the performance of the calibrated and validated SWAT model for Manasgaon watershed was considered as satisfactory.

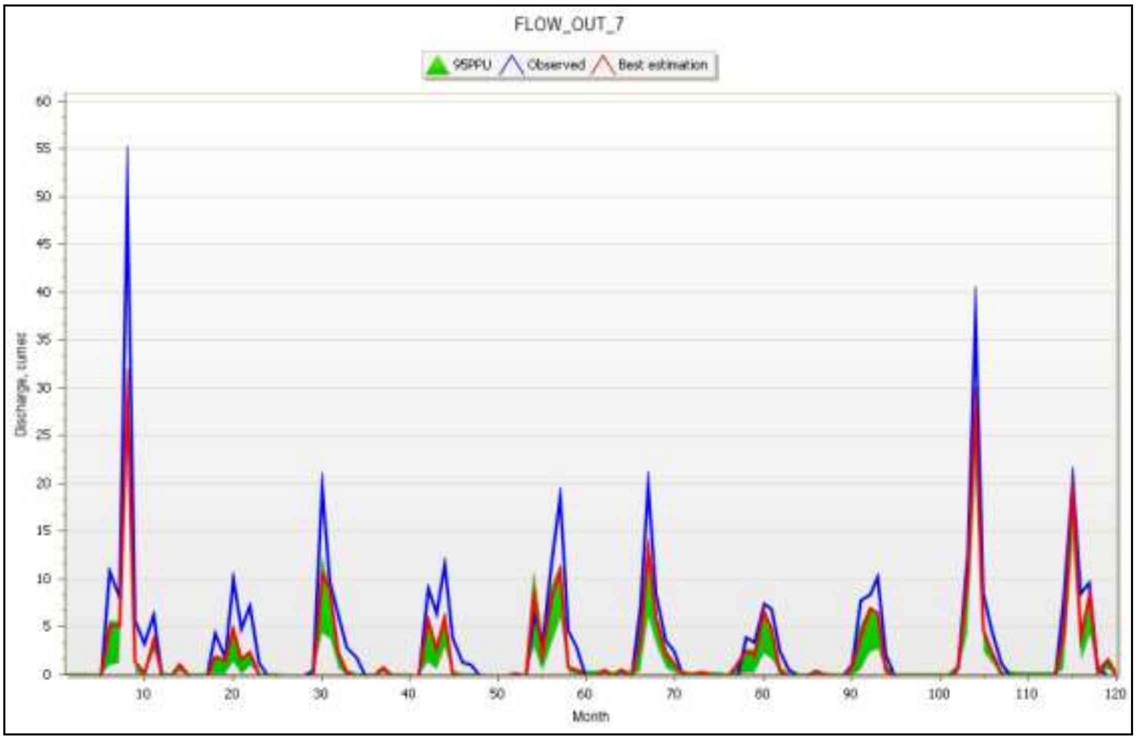

Fig 18: Observed and simulated monthly runoff for the calibration period (1998-2007)

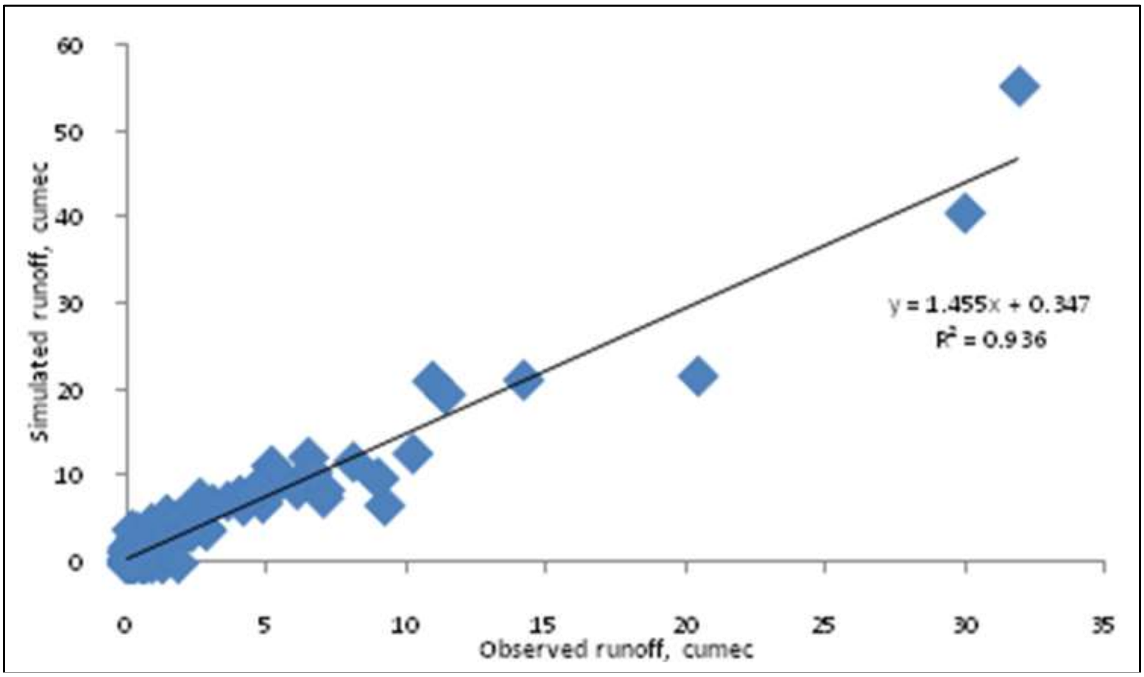

Fig. 19: Scatter plot for the observed and simulated monthly surface runoff during calibration period (1998-2007).

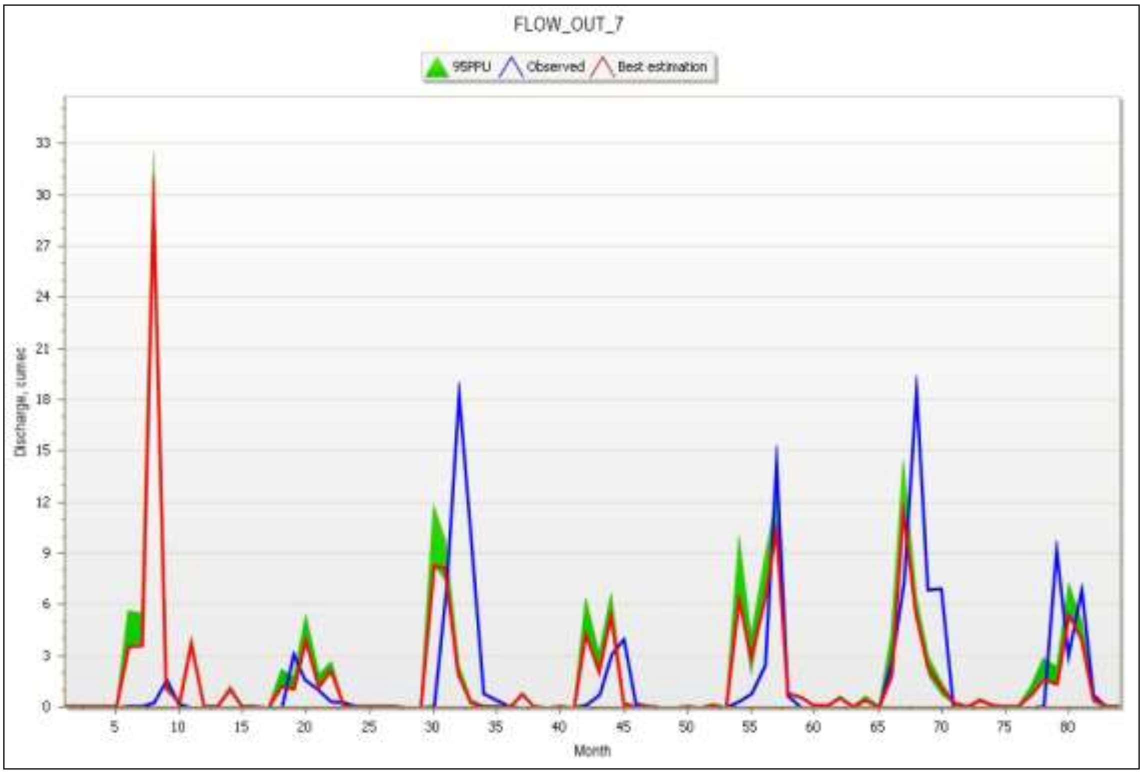

Fig. 20: Observed and simulated monthly runoff for the validation period (2008-2014)

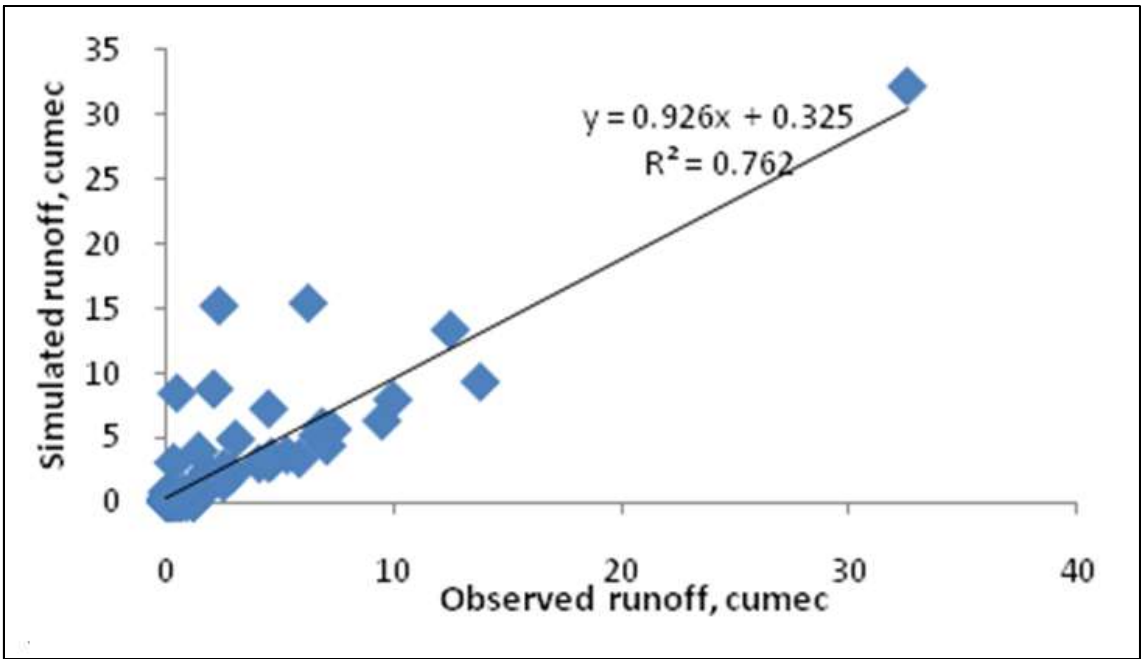

Fig 21: Scatter plot for the observed and simulated monthly surface runoff during validation period (2008-2014).

Water conservation practices for reducing runoff or harvesting runoff

The different water conservation treatments considered based on land use land cover, soil type and slope of the watershed were Conversion of barren land to fair pasture (naturally growing grasses), Contour Farming on agricultural land, strip cropping of agricultural land, terracing and farm pond. The effect of individual treatment was studied by modifying the SCS CN II and USLE_P factor as suggested by Wischmeier and Smith, (1978) [41] and Arabi *et al*. (2004 and 2008) [4, 5]. The modification of these values were made in .mgt file of the SWAT model. The parameters in *.pnd file representing pond were modified as given in SWAT 2002 users manual. The effectiveness of conservation practices that are implemented within agricultural fields or watershed was evaluated by comparing model simulations with no practice and simulations with the practice.

Table 4: Estimated Average annual run off and effectiveness (r) of different scenario for different sub basins.

Sub Basin	Baseline (y_1) Avg. annual runoff, mm	Average annual runoff After Treatment (y_2), mm					Effectiveness, % $((y_1-y_2)/y_1)*100$				
		S-1	S-2	S- 3	S- 4	S- 5	S-1	S-2	S- 3	S- 4	S- 5
1	267.68	267.68	230.84	237.02	246.69	267.42	0.00	13.76	11.45	7.84	0.10
2	329.94	297.55	281.97	307.08	316.46	329.72	9.82	14.54	6.93	4.08	0.06
3	288.97	288.97	284.37	270.26	277.31	288.07	0.00	1.59	6.47	4.03	0.31
4	279.28	279.28	235.72	254.48	263.22	276.87	0.00	15.6	8.88	5.75	0.86
5	264.32	264.32	252.72	241.43	249.75	261.46	0.00	4.39	8.66	5.51	1.08
6	238.56	238.56	225.02	208.20	216.66	238.46	0.00	5.68	12.73	9.18	0.04
7	249.30	247.26	220.52	213.50	223.89	194.65	0.82	11.54	14.36	10.19	21.92
8	235.76	235.76	218.12	205.30	212.39	227.80	0.00	7.48	12.92	9.91	3.38
9	342.73	285.37	299.31	326.71	333.79	342.56	16.74	12.67	4.67	2.61	0.05
10	255.98	255.98	243.98	227.76	231.46	252.54	0.00	4.69	11.03	9.58	1.34
11	238.63	223.49	234.43	209.93	215.07	236.02	6.35	1.76	12.03	9.87	1.09
12	190.94	190.94	188.44	156.65	159.68	135.37	0.00	1.31	17.96	16.37	29.10
13	276.94	276.94	255.46	250.33	252.59	248.49	0.00	7.76	9.61	8.79	10.28
14	284.70	284.70	266.62	257.78	265.22	284.26	0.00	6.35	9.45	6.84	0.16
15	290.48	290.48	270.02	258.97	267.06	288.01	0.00	7.04	10.85	8.06	0.85
16	310.93	301.61	263.42	293.54	295.61	286.09	3.00	15.28	5.59	4.92	7.99
17	303.25	288.71	290.49	270.08	276.92	303.09	4.79	4.21	10.94	8.68	0.05
18	296.93	296.93	281	274.25	278.84	296.64	0.00	5.36	7.64	6.09	0.10
19	296.94	296.94	278.9	274.25	278.84	296.76	0.00	6.07	7.64	6.09	0.06
20	291.36	267.24	272.19	265.56	267.16	291.33	8.28	6.58	8.86	8.30	0.01
21	321.65	289.29	286.91	299.67	305.32	319.81	10.06	10.80	6.83	5.08	0.57
22	246.98	246.98	242.78	212.33	227.46	246.70	0.00	1.70	14.03	7.91	0.11
23	240.39	240.39	236.25	205.80	212.44	240.28	0.00	1.73	14.39	11.63	0.05
24	284.71	284.71	268.54	257.79	265.22	284.65	0.00	5.68	9.45	6.84	0.02
25	275.22	275.22	264.1	248.97	254.75	275.14	0.00	4.04	9.54	7.43	0.03
Avg.	276.10	268.61	255.68	249.11	255.75	263.37	2.71	7.10	9.78	7.37	4.61

(S-1: Conversion of barren land to fair pasture, S-2: Contour Farming, S-3: Strip Cropping, S-4: Terracing, S-5: Farm pond)

Impact of individual water conservation measure on runoff potential

The average annual runoff from Manasgaon watershed before treatment (Baseline) and after implementation of different treatments is summarized in table 4 and figure 22. It is observed from table 4 that, the baseline average annual runoff from the Manasgaon watershed was 276.10 mm (Scenario-0). The simulated average annual runoff after implementation of Scenario -1, 2, 3, 4 and 5 reduced to 268.61 mm, 255.68 mm, 249.11 mm, 255.75 mm and 263.37 mm respectively which was 2.71, 7.10, 9.78, 7.37 and 4.61 per cent less as compared to baseline runoff respectively. The strip cropping treatment was found more effective in reducing runoff (9.78 per cent) followed by terracing (7.37 per cent), Contour farming (7.10 per cent), farm pond (4.61 per cent) and conversion of barren land to fair pasture (2.71 per cent) (figure 22).

Optimization of water conservation strategies

The impact of different water conservation strategies were tested for their effectiveness in reducing runoff or harvesting water. The optimization of different water harvesting strategies i.e., runoff reducing measures was carried out by simulating the combination of different strategies through SWAT model. The ten combinations of different water conservation strategies (table 5) were simulated for runoff estimation and compared with baseline situation. The location specific water conservation strategies (WCS) studied are shown in table 5. Their effectiveness in reducing runoff (mm) over the baseline situation is also depicted in table 6.

Table 5: Water Conservation Strategies (WCS) for different Sub basins

Sr. No.	Scenario	Particulars
1	WCS - 0	- Baseline
2	WCS - 1	- Barren land to fair pasture + Contour farming on Agril. land
3	WCS - 2	- Barren land to fair pasture + Contour farming on Agril. land + Farm pond
4	WCS - 3	- Barren land to fair pasture + Contour farming on Agril. land (0-2 per cent and 2-4 per cent) + Terracing (4-8 per cent)
5	WCS - 4	- Barren land to fair pasture + Contour farming on Agril. land (0-2 per cent and 2-4 per cent0 + Terracing (4-8 per cent) + Farm pond
6	WCS - 5	- Barren land to fair pasture + Strip cropping
7	WCS - 6	- Barren land to fair pasture + Strip cropping + Farm pond
8	WCS - 7	- Barren land to fair pasture + Strip cropping (0-2 per cent, 2-4per cent)+ Terracing (4-8 per cent)
9	WCS - 8	- Barren land to fair pasture + Strip cropping (0-2 per cent, 2-4per cent)+ Terracing (4-8 per cent) + Farm pond
10	WCS - 9	- Barren land to fair pasture + Strip cropping (0-2 per cent) + contour farming (2 -4 per cent) + Terracing (4-8 per cent)
11	WCS - 10	- Barren land to fair pasture + Strip cropping (0 - 2 per cent) + contour farming (2 - 4 per cent) + Terracing (4-8 per cent) + Farm pond

The CN-2 as suggested by Arabi *et al*., 2008 [5] and USLE_P values as given by Wischmeier and Smith, 1978 [41] were modified in the model. The SWAT model was run with modified parameters. The sub basinwise simulated runoff for the different water conservation strategies were compared with baseline runoff i.e., without treatment and the effectiveness was calculated and given in Table 6 and fig. 23.

From the simulated average annual runoff from Manasgaon watershed it was observed that the scenario WCS-10 (i.e., conversion of barren land to fair pasture, strip cropping on agricultural land (0-2 per cent slope), contour farming (2-4 per cent slope), terracing (4-8 per cent slope) and farm ponds in all sub basins) showed maximum per cent reduction in runoff (24.34 per cent) followed by scenario WCS-6 (i.e., conversion of barren land to fair pasture, strip cropping on agricultural land and farm ponds in all sub basins) (23.63 per cent), WCS-8 (i.e., conversion of barren land to fair pasture, strip cropping on agricultural land (0-2 per cent and 2-4per cent slope), Terracing (4-8 per cent slope) and farm ponds in all sub basins) (23.08 per cent). It was also observed that the combination of different treatments was more effective in reducing runoff than individual treatment.

Table 6: Effectiveness of different water conservation strategies for different sub basins.

Sub Basin	Effectiveness, % $((y_1-y_2)/y_1)*100$									
	WCS - 1	**WCS - 2**	**WCS - 3**	**WCS - 4**	**WCS - 5**	**WCS - 6**	**WCS - 7**	**WCS - 8**	**WCS - 9**	**WCS - 10**
1	8.90	9.54	9.20	9.84	24.22	25.34	23.66	24.78	24.30	25.41
2	12.75	13.59	12.75	13.59	17.00	18.18	15.80	16.89	17.61	18.84
3	2.61	3.44	2.61	3.44	9.98	11.00	9.98	11.00	9.98	11.00
4	6.78	8.36	6.78	8.36	18.41	20.97	18.41	20.97	18.41	20.97
5	3.38	5.67	3.38	5.67	12.11	15.29	12.11	15.29	12.11	15.29
6	10.03	10.52	10.03	10.52	27.95	29.07	27.95	29.07	27.95	29.07
7	8.91	25.18	10.65	26.40	19.28	31.83	17.12	30.86	21.97	33.40
8	8.38	13.52	8.38	13.52	26.08	32.20	26.08	32.20	26.07	32.20
9	13.90	14.26	13.90	14.26	17.01	17.36	17.01	17.36	17.01	17.36
10	4.04	6.11	5.78	7.96	16.84	19.75	16.84	19.75	18.20	21.22
11	13.87	16.34	14.80	17.33	25.09	28.30	23.09	26.19	25.40	28.64
12	8.76	36.01	12.15	38.39	28.78	48.54	26.85	47.21	31.20	50.15
13	5.83	19.08	5.83	19.08	18.36	32.25	18.36	32.25	18.36	32.25
14	6.51	7.69	6.51	7.69	18.88	20.99	18.88	20.99	18.88	20.99
15	5.38	7.17	6.08	7.90	16.62	19.25	15.23	17.75	16.85	19.50
16	4.93	13.59	6.20	14.95	9.59	18.26	8.79	17.73	10.50	19.06
17	9.41	10.05	11.79	12.58	19.35	20.68	18.16	19.41	20.95	22.41
18	1.89	2.65	1.89	2.65	10.15	11.41	10.15	11.41	10.15	11.41
19	1.89	2.35	1.89	2.35	10.15	10.60	10.15	10.60	10.15	10.60
20	10.29	10.36	12.59	12.66	17.48	17.54	16.96	17.03	19.61	19.71
21	14.22	16.35	14.22	16.35	20.21	22.79	20.21	22.79	20.21	22.79
22	14.33	15.73	14.33	15.73	36.22	38.40	36.22	38.40	36.22	38.40
23	8.88	9.42	11.91	12.61	27.98	29.19	27.98	29.19	30.53	31.86
24	6.51	6.67	6.51	6.67	18.88	19.01	18.88	19.01	18.88	19.01
25	5.59	5.82	5.59	5.82	17.73	17.91	17.73	17.91	17.73	17.91
Average	9.18	11.20	10.15	13.98	19.81	23.63	19.18	23.08	20.59	24.34

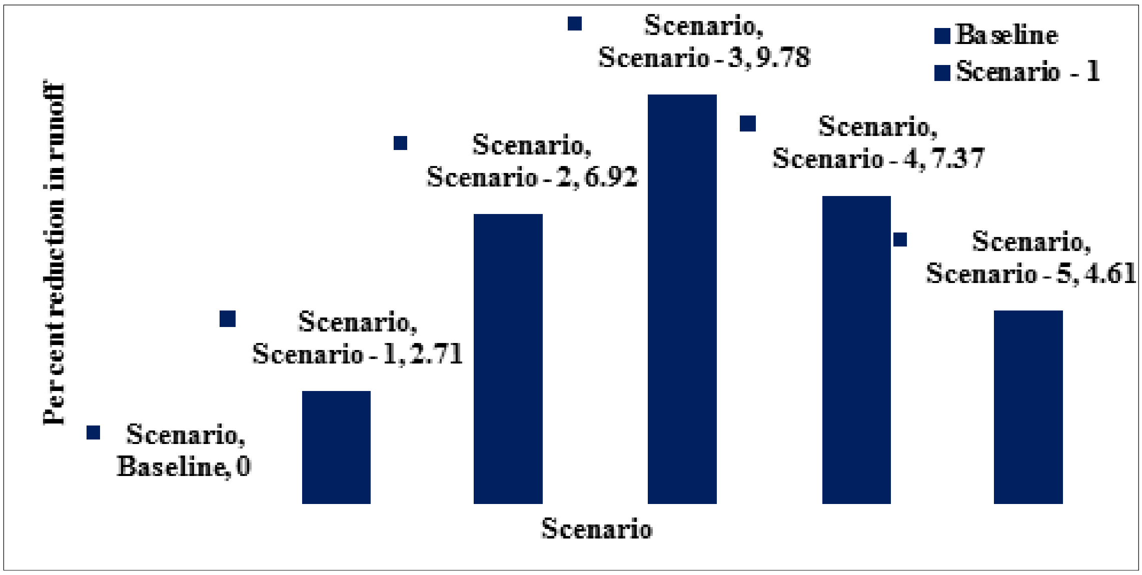

Fig 22: Effectiveness of different treatments in runoff reduction from Manasgaon watershed.

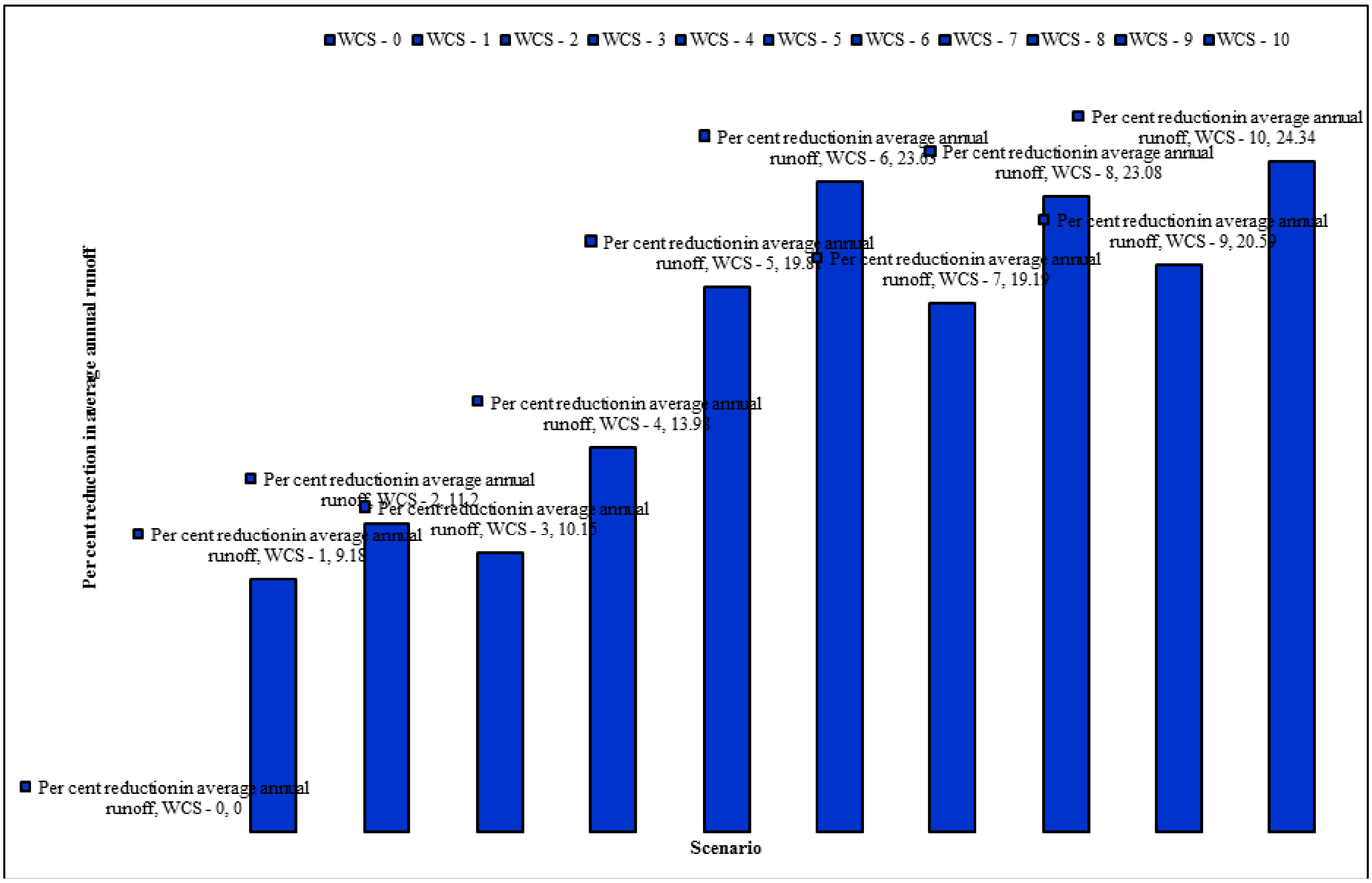

Fig 23: Per cent reduction in average annual runoff due to different water conservation strategies (WCS) for Manasgaon watershed

Conclusion

The SUFI-2 technique of SWAT CUP was found very useful tool in sensitivity analysis of the parameters, calibration and validation of the SWAT model for Manasgaon watershed. The strip cropping treatment was found more effective in reducing runoff followed by terracing, contour farming, farm pond and conversion of barren land to fair pasture. It has been also concluded that the scenario WCS-10 (i.e., conversion of barren land to fair pasture, strip cropping on agricultural land (0-2 %), contour farming (2-4 per cent slope), terracing (4-8 per cent slope) and farm ponds in all sub basins) is found more effective in reducing runoff. The combined effect of different treatments is more effective in reducing runoff than individual effect of each treatment. The calibrated and validated SWAT model can be effectively used for simulation and optimization of different climate resilient water conservation strategies for Manasgaon watershed under changing climate scenario.

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