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Hydrologic Assessment in a Middle Narmada Basin, India using SWAT Model

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ABSTRACT

Narmada, a river in central India flows in a rift valley through the state of Madhya Pradesh, Maharashtra and Gujarat, plays an important role for water supply and ground water recharge. Therefore water resource management and planning can be improved in a rift valley after accurate simulation of hydrological assessment. In this study the Soil and Water Assessment Tool (SWAT) used on middle Narmada basin. The basic objective of the present study is to derive parameters required for runoff modeling using the Remote Sensing and Geospatial database and estimate surface runoff of middle Narmada basin. The main input data for simulation of SWAT containing Digital Elevation Model (DEM), Land Use/Land Cover (LU/LC), Soil type, Soil properties and Hydro-climatologically data, were appropriately collected. By providing all inputs for model set up, SWAT model was simulated for the period of 12 years (1997-2008) and Validated with 2009 and 2010 year separately. The results indicated that 46% of the annual precipitation is lost by evapotranspiration in the basin.

Key Words: SWAT Model, Remote Sensing, GIS, HRU, SUFI-2, SWAT-CUP

INTRODUCTION

Water is one of the most important substances on earth. All plants and animals must have water to survive. If there was no water there would be no life on earth. Apart from drinking it to survive, people have many other uses of water for basic needs. India is the second most populous country in the world. By the middle of this century it needs to feed an extra population of 500 million. Second, India has had a huge economy and a remarkable economic growth in the last decade. With the booming economy, people's expenditure patterns are changing; rapid urbanization is also adding fuel to these changes. The changing food consumption patterns are so significant that they have a considerable impact on the needs of future food and water demand. In India there are significant spatial mismatches of the population and water resources. Less water is available in places where more people live and much of the food is grown. Some river basins are already experiencing physical water scarcities. A few others face problems of unsuitable groundwater use. Thus, how India meets its increasing food and water demand was the major focus of many recent food and water demand projections at the global scale (IWMI 2000) and the national scale.

Table 1: Water requirement for different uses (Cu Kms.) in India

Use	Year			
	2000	2010	2025	2050
Irrigation	524	557	618	807
Domestic	30	43	62	111
Industry	30	37	67	81
Power	9	19	33	70
Ecology	0	5	10	20
Evaporation	36	42	50	76
Total	**629**	**710**	**850**	**1180**

The present study uses the Remote Sensing and GIS techniques to assess the water balance simulated with SWAT Model and compared measured and simulated streamflow.

2. MATERIALS & METHODS

2.1 Study Area:

The **Narmada**, also called the *Rewa*, is a river in central India and the fifth longest river in the Indian subcontinent. It is the third longest river that flows entirely within India, after the Godavari and the Krishna. It forms the traditional boundary between North India and South India and flows westwards over a length of 1,312 km before draining through the Gulf of Khambhat into the Arabian Sea. It is one of only three major rivers in peninsular India that run from east to west (longest west flowing river), along with the Tapti River and the Mahi River. It is the one of the rivers in India that flows in a rift valley, flowing west between the Satpura and Vindhya ranges.

The Narmada River rises in the Amarkantak Plateau of Maikala range in the Shahdol district of Madhya Pradesh at an elevation of 1057 meters above mean sea level at latitude 22° 40' north and a longitude of 81° 45' east. The river travels a distance of 1,312 km before it falls into Gulf of Cambay in the Arabian Sea near Bharuch in Gujarat. The first 1,079 km of its run are in Madhya Pradesh. The study Area lies in the Middle Narmada Basin which is located Southern part of Madhya Pradesh with extent of 21^0 25’ 44” N to 23^0 06’ 19” N Latitude and 74^0 13’ 55” E to 77^0 48’ 29” E Longitude.

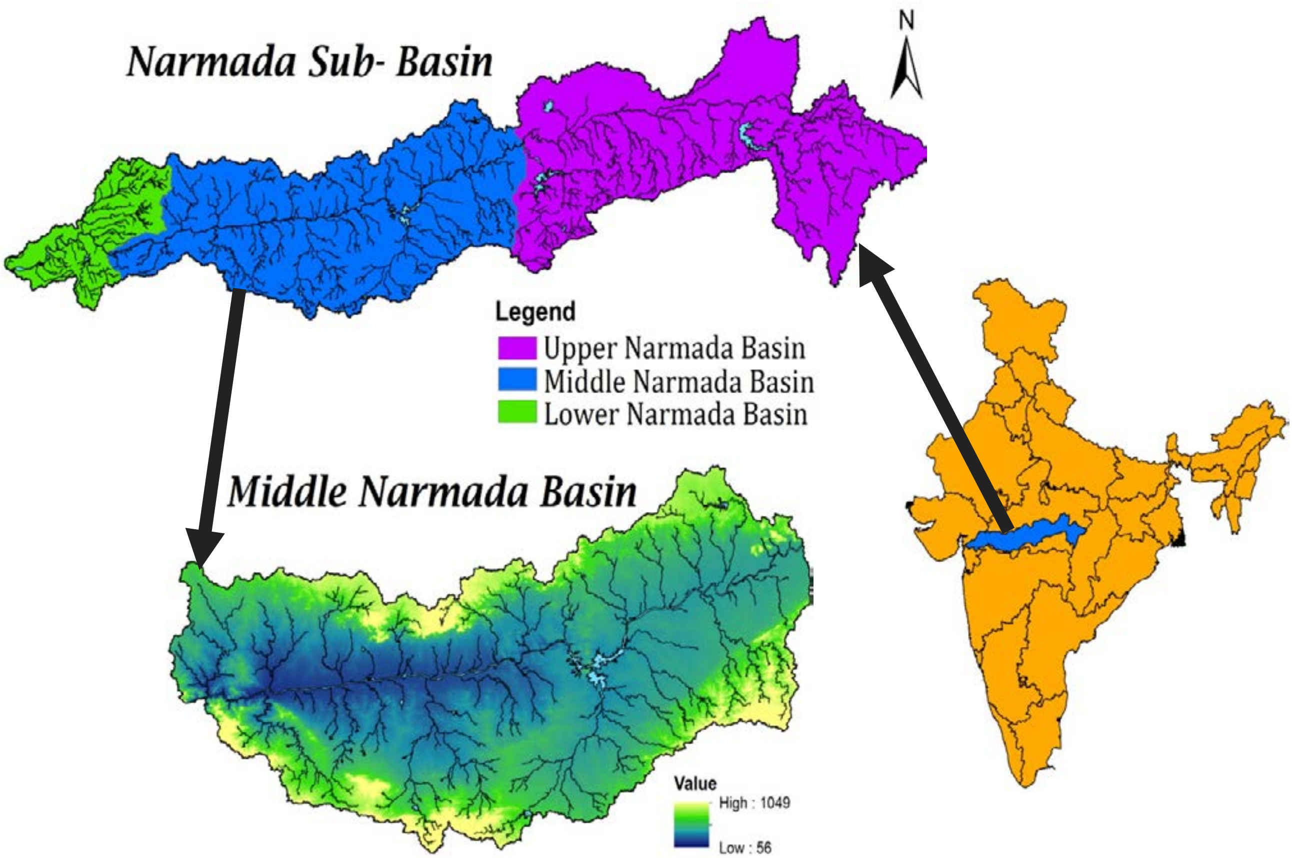


Figure 1: Location map of study Area

2.2 Input Data:

The present study focus on the application of SWAT 2012 in the Middle Narmada basin to observe the influence of topographic, landuse, soil and climatic condition etc. on stream flow. Data were collected from various sources and different processes have been carried out.

Table 2: Data Sources for Simulation of SWAT Model for Middle Narmada Basin

Data	Location	Period of Records	Supplying Agency
Digital Elevation Model (30m)	Basinwide (Middle Narmada Basin)	Unknown	ASTER DEM, Japan Space Systems
Soil Map (Hard Copy) (1:50000)	Madhya Pradesh	1996	NBSS & LUP, Nagpur
Land use/ Land Cover Map	Madhya Pradesh	2010	NRSA, Hyderabad
Rain-gauge	45 Stations	1995-2010	IMD, New Delhi
Ground Water	118 Wells	2007-2011	CGWB, New Delhi
River Discharge Data	2 stations	2000-2010	CWC, Bhopal
Max. Min. Temperature, Relative Humidity, Solar radiation, Wind Speed	45 Stations	1995-2010	Global Data (http://globalweather.tamu.edu/)

A. Digital elevation Model (DEM):

Topography was defined by a DEM that describes the elevation of any point in a given area at a specific spatial resolution. A 30 m X 30 m resolution DEM was downloaded from ASTER DEM website for the study area. The DEM was used to delineate the watershed and to analyze the drainage patterns of the land surface terrain. Subbasin parameters such as slope and the stream network characteristics such as slope, length and width were derived from the DEM.

Figure 2: ASTER DEM data 30m resolution (Source: Japan Space Systems)

B. Land use Map:

Land use/Land cover map for the study area has been downloaded from Bhuvan database maintained by National Remote Sensing Agency (NRSA), Hyderabad.

C. Soil Database:

SWAT model requires different soil textural and physicochemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. The Soil Map (Hard Copy) on 1:50,000 scale and soil Characteristics data were obtained from the NBSS & LUP, Nagpur. The Soil Map is then digitized appropriately for making geospatial database. Major soil types in the basin are Clayey, Loamy, and Loamy-Skeletal soil.

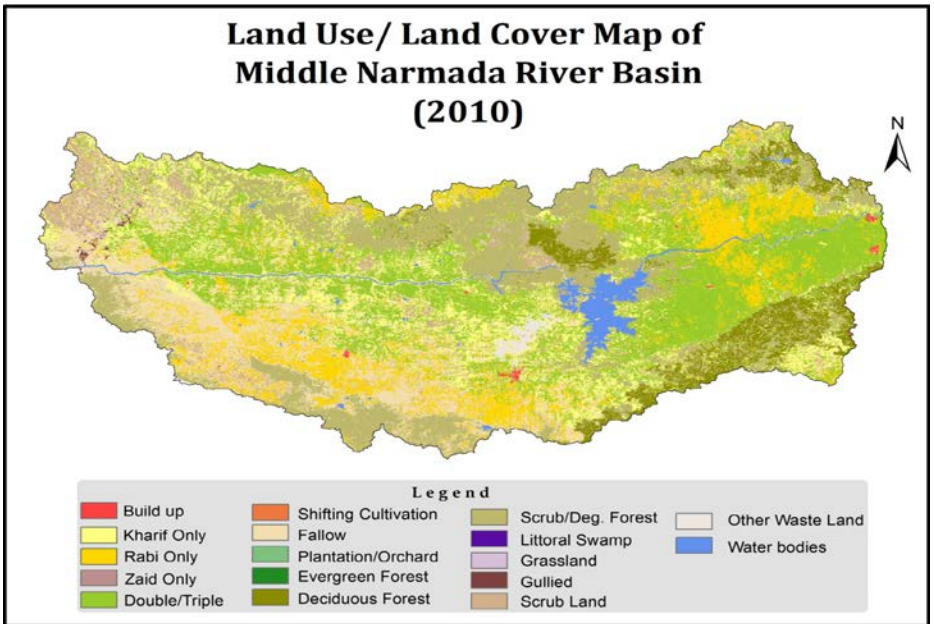


Figure 3: Land use/Land Cover Map (Source: NRSA, Hyderabad)

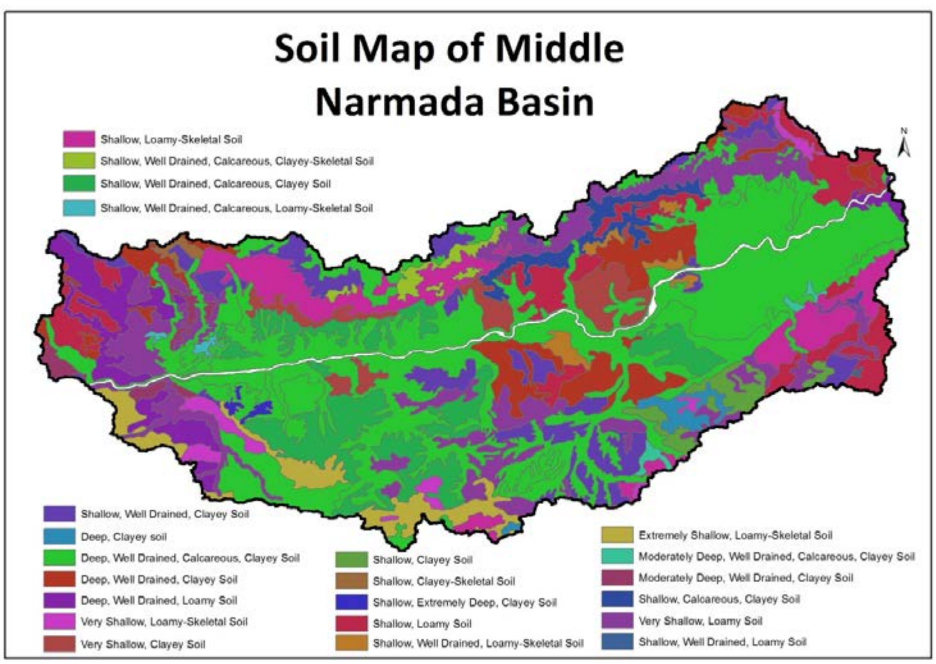


Figure 4: Soil Map (Source: Hard Copy Map from NBSS & LUP, Nagpur)

D. Weather Database:

SWAT requires daily meteorological data that can either be read from measured data set or be generated by a weather generator model. The weather variables used in this study for driving the hydrological balance are daily precipitation, minimum and maximum air temperature for the period 1995-2010. Rainfall data were obtained from India Meteorological Department, New Delhi. For maximum minimum Temperature, Relative Humidity, Solar radiation and Wind Speed data were downloaded from global data website http://globalweather.tamu.edu

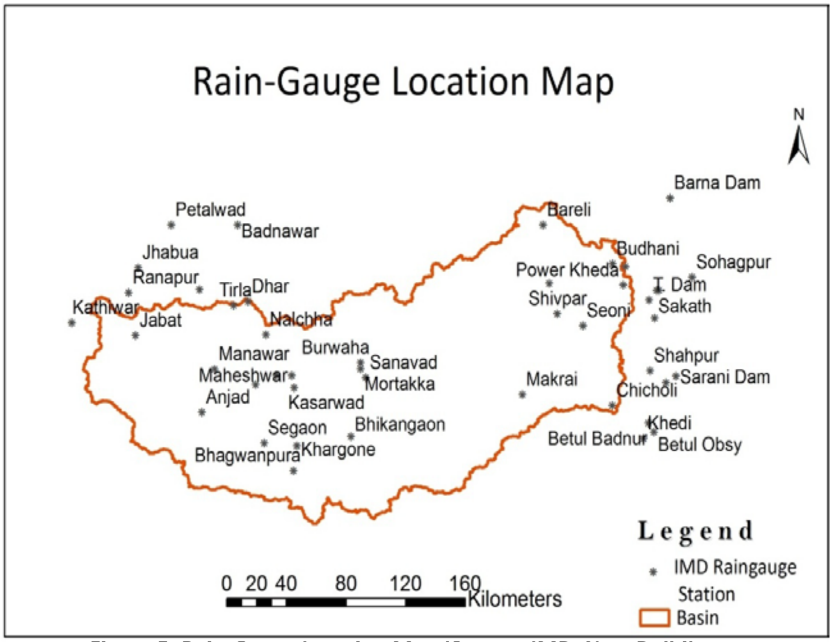


Figure 5: Rain-Gauge Location Map (Source: IMD, New Delhi)

E. River Discharge Map:

Daily River Discharge values for Narmada River at Hoshangabad and Garudeshwar were obtained from CWC, Bhopal

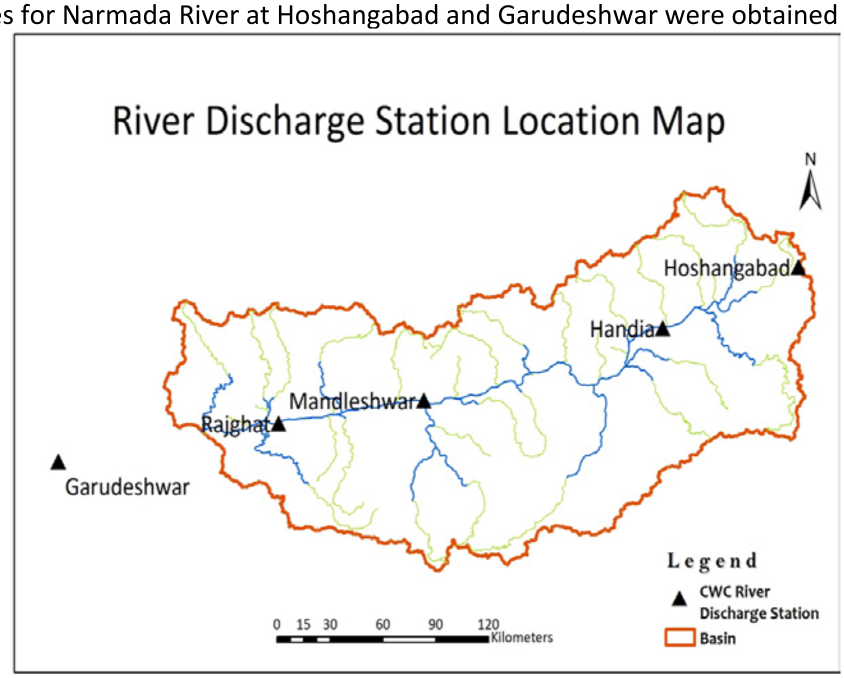


Figure 6: River Discharge Stations Location Map (Source: CWC, Bhopal)

F. Ground water data:

Ground water data for the study area were obtained from Central Water Ground Board, New Delhi for 118 wells.

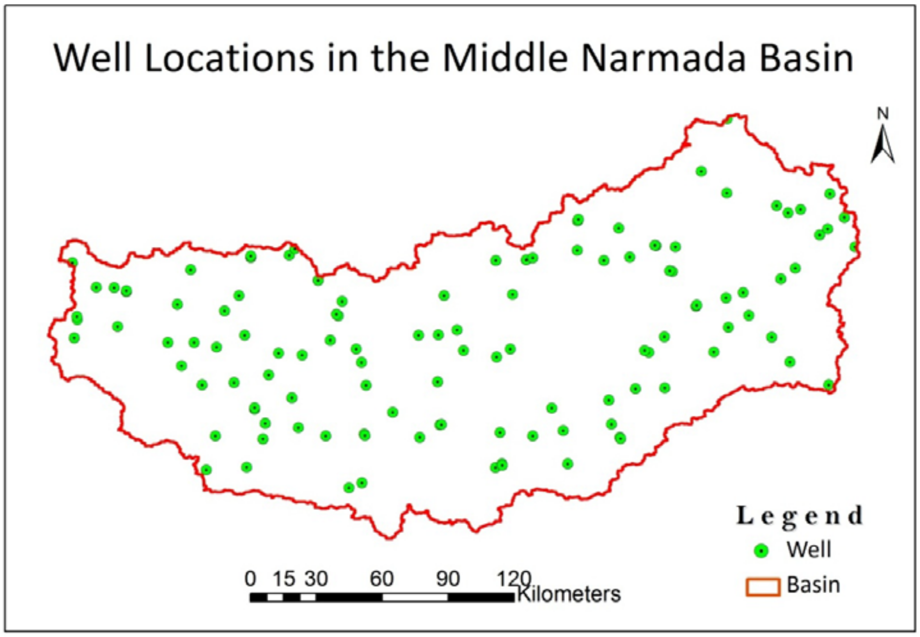


Figure 7: Well Locations in Middle Narmada Basin (Source: CGWB, New Delhi)

2.3 SWAT Model Setup:

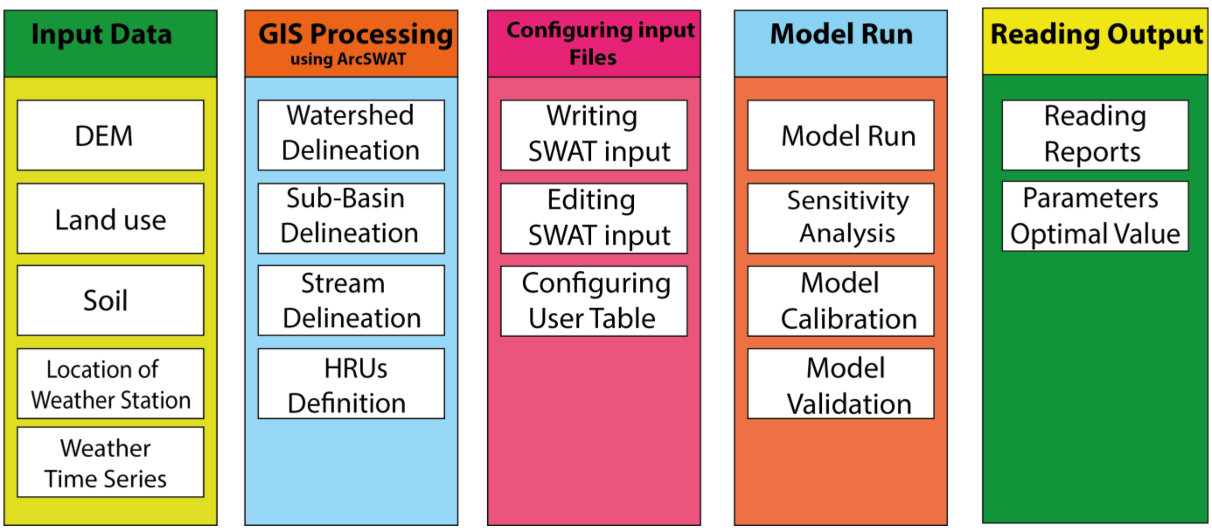


Figure 8: Components and Input/output data of SWAT Model

SWAT is a continuous time spatially distributed model designed to simulate water, sediment, nutrient and pesticide transport at a catchment scale on a daily time step. It uses hydrologic response units (HRUs) that consist of specific land use, soil and slope characteristics. The HRUs are used to describe spatial heterogeneity in terms of land cover, soil type and slope class within a watershed. The SWAT model is being used to estimate runoff of the Middle Narmada basin. At first, setup for new SWAT project has been created. ASTER data had a geographic coordinate system so it was converted into projected coordinate system by using ArcMap 10 and then imported in the SWAT project to delineate watershed.

A. Stream Definition:

In this section, DEM based stream definition is calculated using Flow direction and accumulation method. Then stream network and sub-basin outlets were defined.

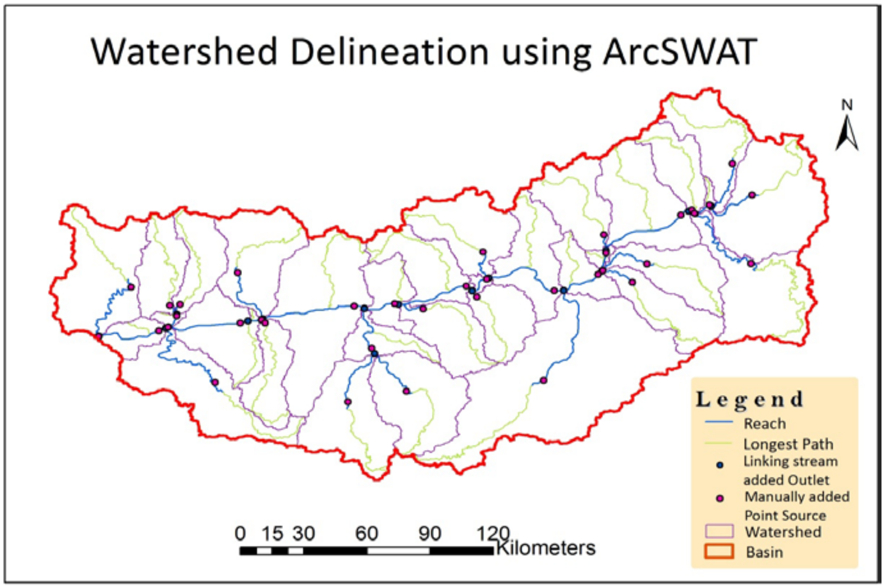


Figure 9: Watershed Delineation using ArcSWAT

B. Hydrologic Response Unit (HRU) Analysis: Defining land use/soil data/Slope

Under HRU Analysis, for each of the delineated sub-basins, Land use, Soil data and Slope were defined for modeling of various hydrological and other physical processes. For creating HRU we give the 20% for Land use, 20% for Soil and 5% for slope threshold value.

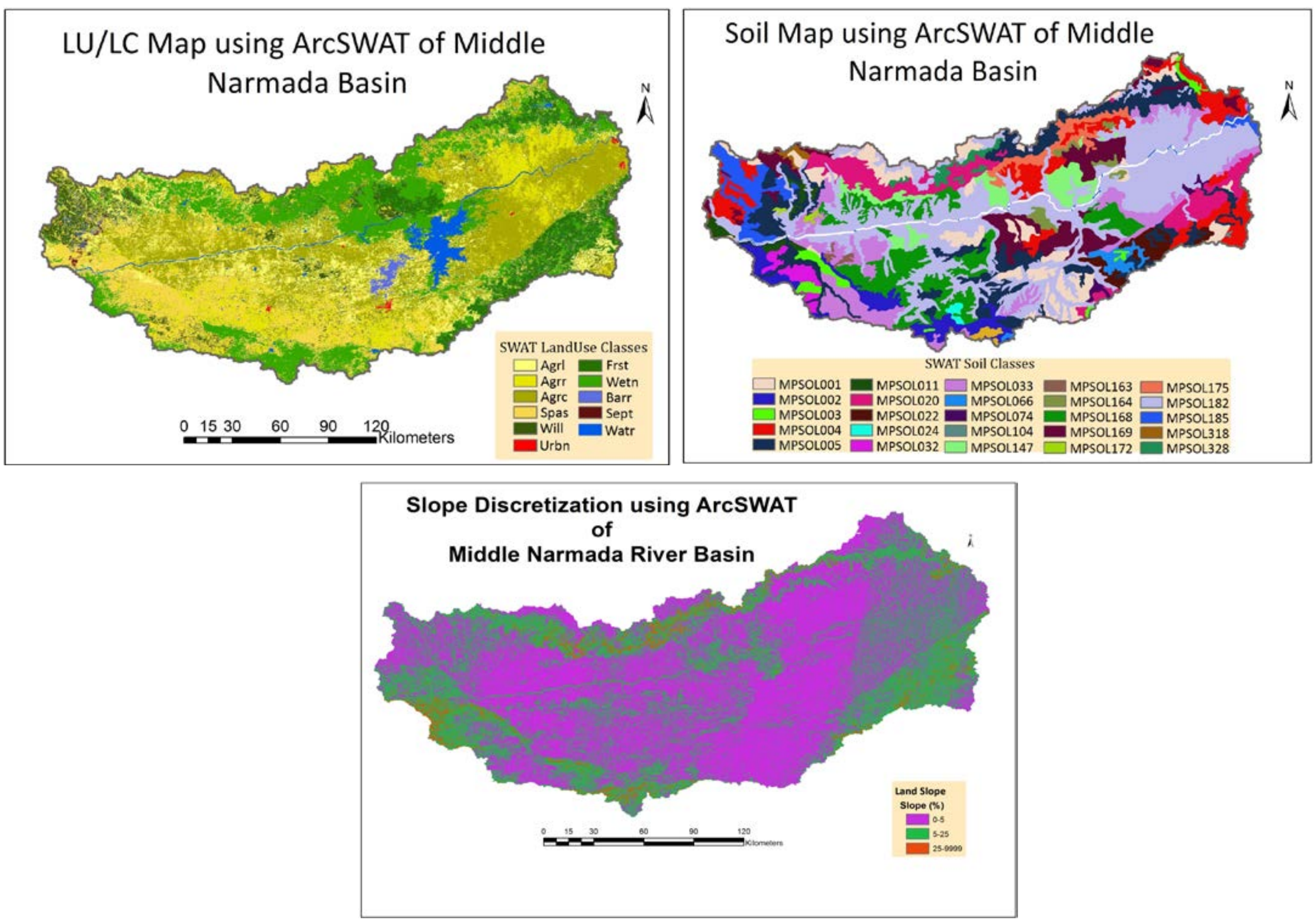


Figure 10: SWAT LU/LC Map/Soil Map/Slope Map

3. RESULTS AND DISCUSSION

A. Precipitation:

Daily precipitation data of the last 16 years collected from IMD has been converted into GIS format. Monthly and Annual precipitation in the basin has been analyzed. From this data, it is found that precipitation varies temporally and spatially across the basin. More than 85 % of the precipitation takes place during July to September months. Annual precipitation varies from 778 mm to 1389 mm and average annual precipitation of these 16 years is found to be 1035 mm. When spatial variations are considered, some areas receive 2000 mm annual precipitation.

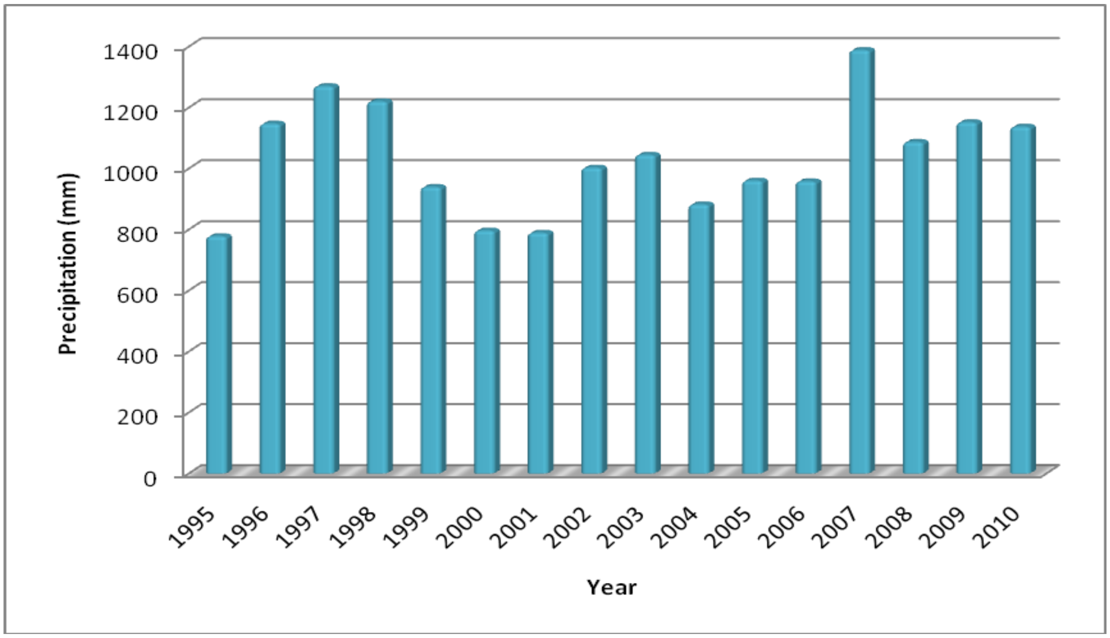
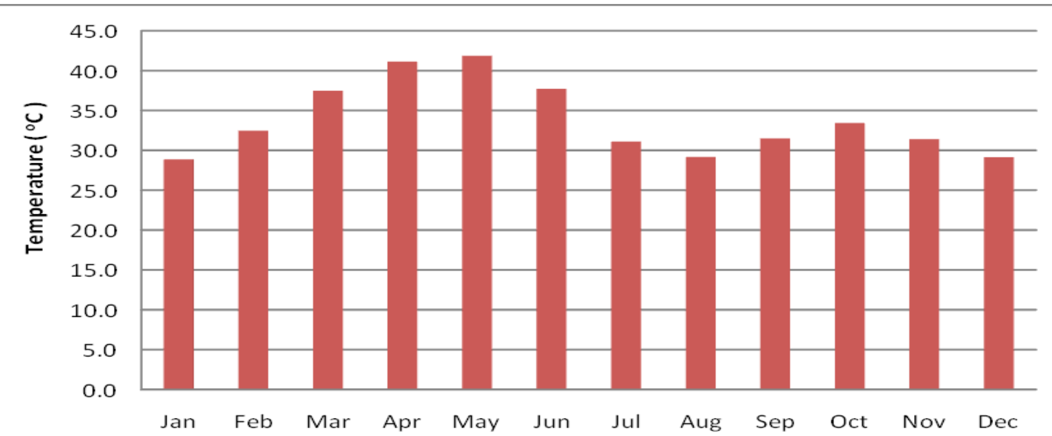


Figure 11: Annual Variations in the Precipitation of the Middle Narmada basin

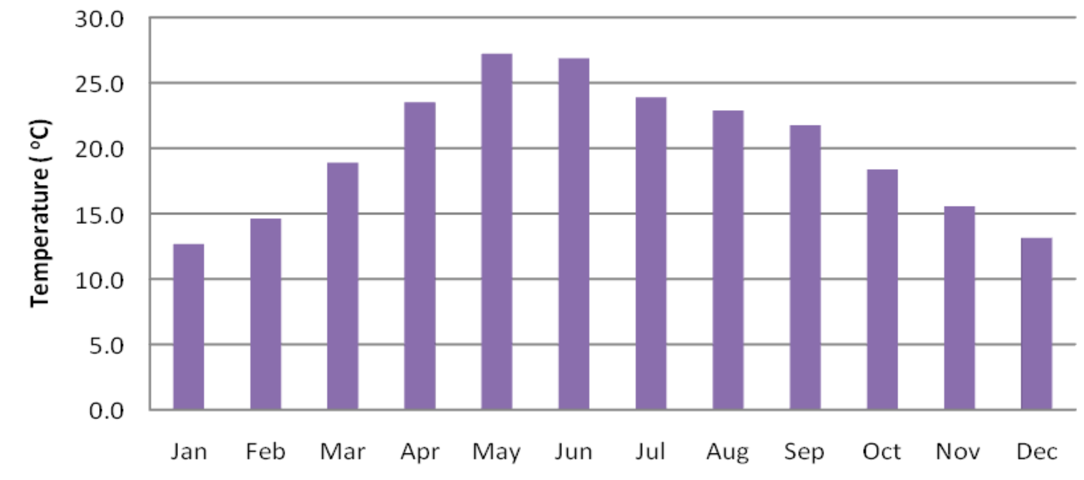
B. Temperature:

A temperature is a numerical measure of hot and cold. Its measurement is by detection of heat radiation, particle velocity; kinetic energy, or most commonly, by the bulk behavior of a thermometric material. The climate of central India is monsoonal and the unique situation of the Narmada basin in between the Satpura and Vindhya ranges results in rainfall and temperature variations. Temperature varies from 12°C to 42 °C in a year which causes lot of monthly variations in the potential evapotranspiration in the basin. The Maximum Average temperature raises from March to May then downfall of temperature till August and again it rises till October.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max Temperature	28.9	32.5	37.5	41.1	41.9	37.7	31.1	29.2	31.5	33.4	31.4	29.1

Figure 12: Month-wise Avg. Maximum Temp.of the Middle Narmada basin



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min Temperature	12.7	14.6	18.9	23.5	27.2	26.9	23.9	22.9	21.8	18.4	15.6	13.1

Figure 13: Month-wise Avg. Minimum Temp.of the Middle Narmada basin

C. Land Use/Land Cover Mapping:

The LISS-III scene covering the study area was classified to obtain landuse-land cover for the year 2010-2011. The areal extents of various landuse/land cover in the study area are given in table.

Table 3: Landuse/ Land cover distribution in the study area and corresponding SWAT Landuse class

Landuse Distribution	Area (%)	SWAT Land use Class
Built-up	0.16	URBN
Kharif only	11.93	AGRL
Rabi only	12.56	AGRR
Double/Triple	24.04	AGRC
Fallow	14.28	PAST
Deciduous Forest	5.97	FRST
Scrub/Degraded forest	20.09	WETN
Wasteland	2.41	BARR
Gullied	0.29	SEPT
Scrubland	5.68	WETL
Waterbodies	2.61	WATR

The area-wise landuse/land cover of study area was computed and then plotted on a pie-graph in figure to show the landuse distribution pattern all over the area.

The majority of the area is under double/Triple cropping system, with nearly 24.04 % of the total area. Kharif and Rabi crop is grown over nearly 11.93 % and 12.56 % respectively. A vast extent of the area is found to be kept currently fallow, to be taken up for a good cultivation. They appear very distinctly on the satellite data. Nearly 20.09 % of the area is under scrub/degraded forest and about 5.97 % under deciduous forest

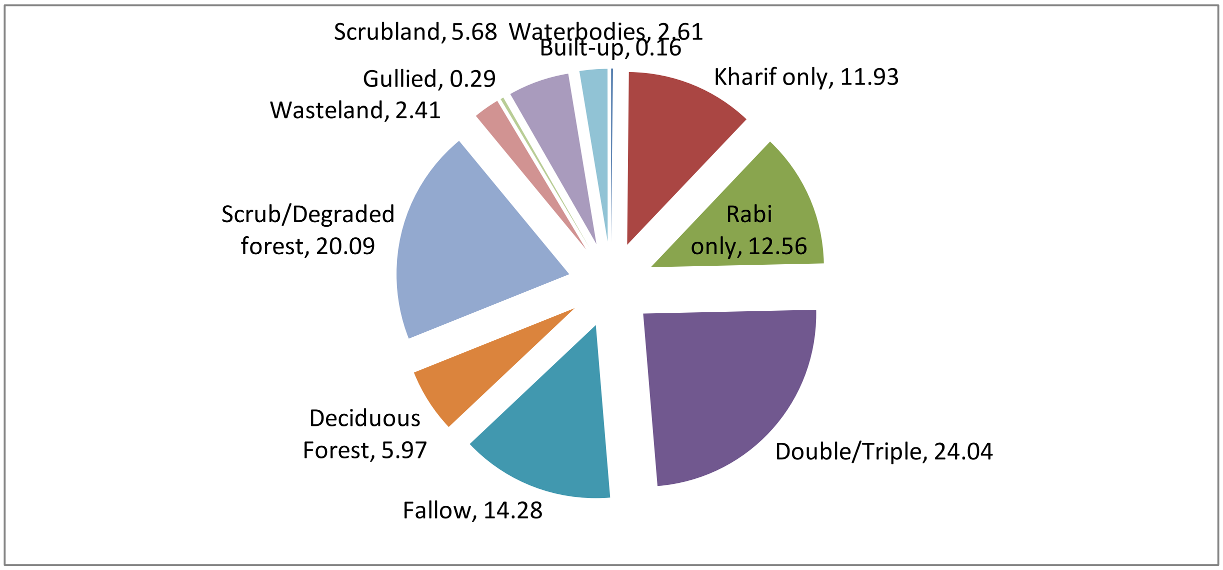


Figure 14: Landuse distribution (Area %)

D. Distribution of Soil Types:

The vector coverage of the soil map (NBSS & LUP) was prepared using the ArcGIS 10 software. Prior to this, the soil map were scanned and then georeferenced. The study area contains soil mapping units.

Table 4: Distribution of Soil Types

Soil Texture	Area (%)	SWAT Land use Class
Shallow, Well Drained, Clayey Soil	6.27	MPSOL001
Extremely Shallow, Loamy-Skeletal Soil	3.42	MPSOL002
Very Shallow, Loamy-Skeletal Soil	1.19	MPSOL003
Shallow, Loamy Soil	6.93	MPSOL004
Very Shallow, Loamy Soil	10.94	MPSOL005
Moderately Deep, Well Drained, Clayey Soil	0.91	MPSOL011
Shallow, Loamy-Skeletal Soil	5.83	MPSOL020
Shallow, Clayey Soil	1.57	MPSOL022
Very Shallow, Loamy-Skeletal Soil	0.23	MPSOL024
Shallow, Loamy-Skeletal Soil	0.31	MPSOL025
Deep, Well Drained, Loamy Soil	1.11	MPSOL032
Deep, Well Drained, Calcareous, Clayey Soil	7.40	MPSOL033
Deep, Clayey soil	0.91	MPSOL066
Moderately Deep, Well Drained, Calcareous, Clayey Soil	0.35	MPSOL074
Shallow, Well Drained, Loamy Soil	0.03	MPSOL104
Very Shallow, Clayey Soil	3.07	MPSOL147
Shallow, Extremely Deep, Clayey Soil	0.23	MPSOL163
Shallow, Well Drained, Loamy-Skeletal Soil	0.88	MPSOL164
Shallow, Well Drained, Calcareous, Clayey Soil	7.58	MPSOL168
Deep, Well Drained, Clayey Soil	5.80	MPSOL169
Shallow, Well Drained, Calcareous, Loamy-Skeletal Soil	0.18	MPSOL172
Shallow, Calcareous, Clayey Soil	1.89	MPSOL175
Deep, Well Drained, Calcareous, Clayey Soil	29.01	MPSOL182
Deep, Well Drained, Loamy Soil	2.85	MPSOL185
Shallow, Clayey-Skeletal Soil	0.29	MPSOL318
Shallow, Well Drained, Calcareous, Clayey-Skeletal Soil	0.83	MPSOL328

E. Ground water:

Groundwater plays a major role in the water resources assessment. Large extent of the agricultural area depends on well irrigation also. Groundwater being exploited to meet the domestic and industrial needs as well in the urban areas of the basin. Annual groundwater flux in the basin varies from +15 m to -25 m. Some packets these fluctuations are more. Annual groundwater table data of 2007 to 2011 (only 5 years data is available) have been obtained from Central Groundwater Board and analyzed. Wells having abnormal fluctuations compared to the surrounding wells are ignored. In total nearly 118 wells have been identified and mapped in GIS environment and shown in the figure. It is found that wells data is not dense in study area. Annual groundwater flux grids during the mentioned period have been computed using the Inverse Distance Weight interpolation method. These interpolated grids are validated randomly. Annual groundwater flux grid of 2007-08 to 2010-11 is shown in the figure.

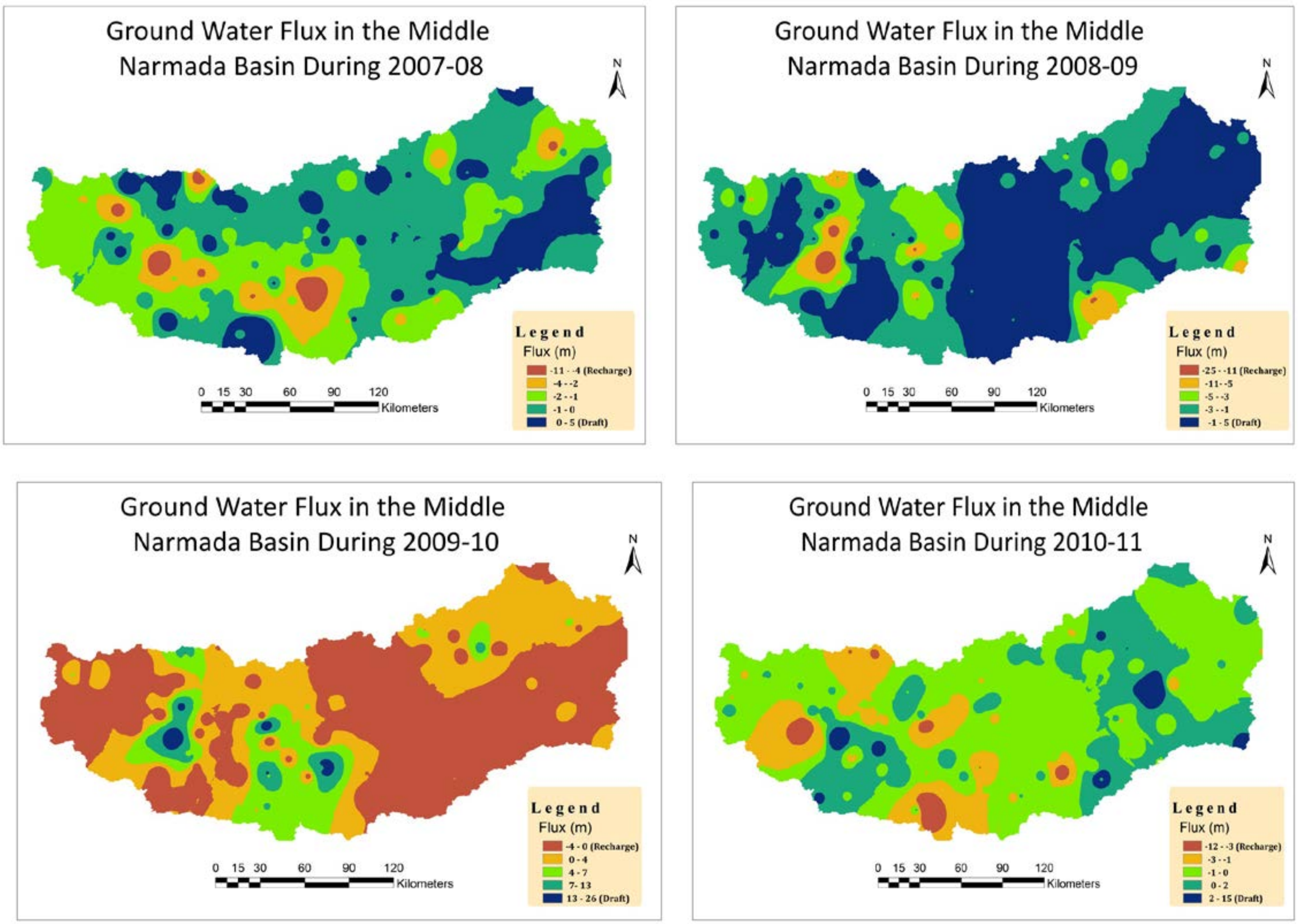
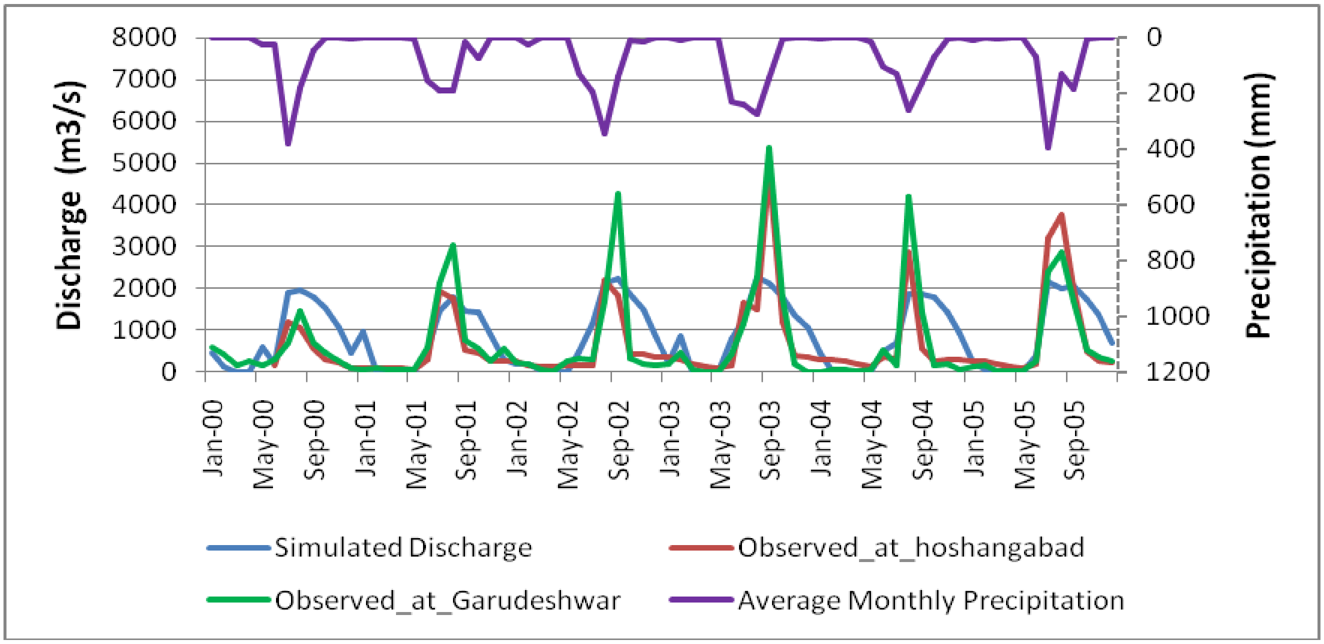


Figure 15: Groundwater Flux in the in the middle Narmada basin from 2007 to 2011

F. Surface Runoff:

The model efficiency was computed using the default simulation result and the measured flow data. It was observed that the threshold area of 39,608 Sq. Km. resulted in 37 subbasins that accounts for the main drainage lines within the watershed. This resulted in a better representation of the hydrological processes and produced streamflow yield which had a better model efficiency in comparison to the measured streamflow. Number of subbasins above this threshold has brought no significant changes in the simulation of streamflow. There are many factors that affect runoff such as climatic and watershed or physiographic factors. SWAT model uses SCS curve number method to calculate the surface runoff that accounts for the precipitation and the retention parameter. The latter parameter is calculated with the value of curve number. The Curve number depends primarily on the soil type, land use and to the lesser extent on slope. The calculation of CN in the basin was adjusted for slope greater than 5 %. Thus, making runoff to be less dependent on subbasin discretization. The analysis of HRU definition indicated that dominant type of HRU definition resulted in a single HRU for each subbasin where the dominant landuse, soil and slope of each subbasin. This single HRU within each subbasin was notable to properly represent the characteristics of the subbasin. Accordingly the simulated streamflow shows unsatisfactory result as compared to the measured stream flows in the study area. The multiple scenarios that accounts for 20% landuse, 20% soil and 5% slope threshold combination gives a better estimation of streamflow in the basin. It resulted in 214 HRUs in the whole basin. This scenario resulted in detailed land use, slope and soil database, containing many HRUs, which in turn represent the heterogeneity of the study area. The distribution of landuse, soil and slope characteristics within each HRU have the greatest impact on the predicted streamflow. As the percentage of landuse, slope and soil threshold increases the actual evapotranspiration. Hence, the characteristics of HRUs are the key factor for affecting streamflow.



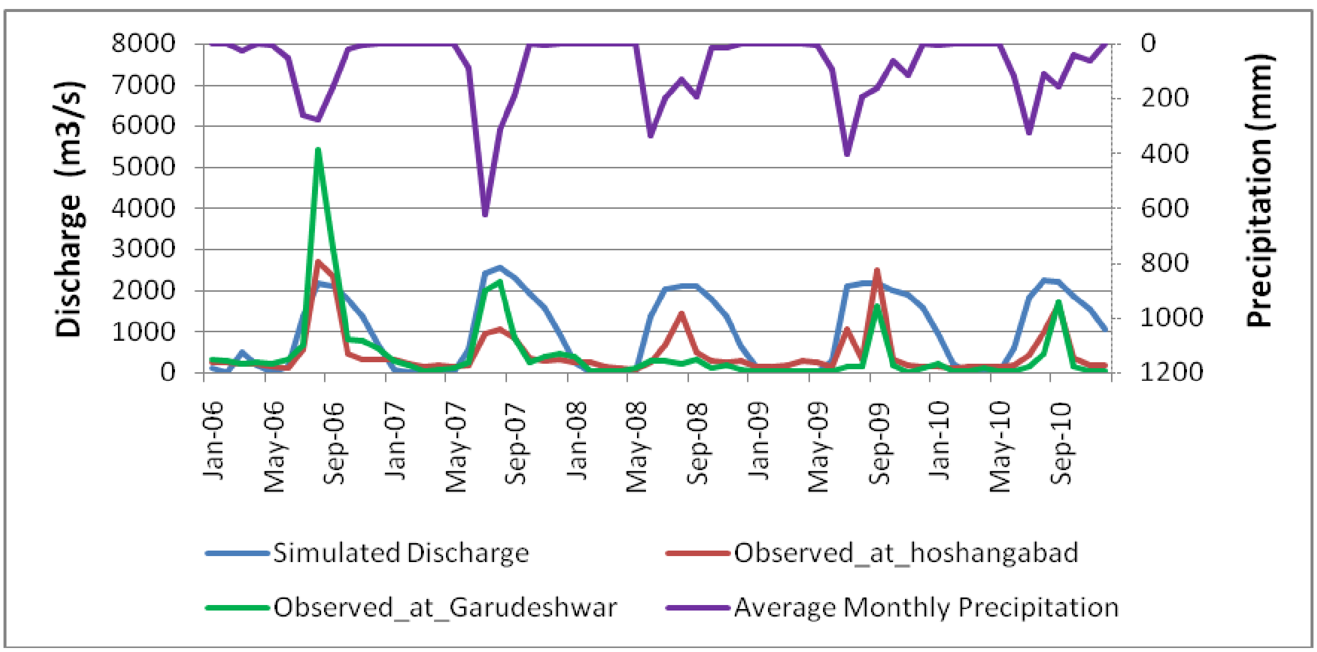


Figure 16: Comparison of Observed (at Hoshangabad and Garudeshwar) and simulated runoff (Q) on the middle Narmada basin

The error in the simulated value due to errors in input data such as precipitation and temperature and or other sources of uncertainties such as upstream dam (Indira Sagar) for irrigation, water supply and other unknown activities in the subbasins. However, the uncertainties may not only depend on precipitation and temperature. We have assumed that the model deficiency in study area could be due to the input uncertainty as well as construction of infrastructures in the upstream of the watershed. However we cannot rule out the possibility of an error in the type of soil and the corresponding soil properties in the area. This can create some uncertainty on the simulated result. Another issue is the soil erosion that affects the structure, infiltration capacity and other properties of the soil. Since the model does not consider the effect of soil erosion on runoff, the predictions can be uncertain. Table 5 lists various performance statistics for calibration (1997-2008) and Validation (2009 & 2010) years. Based on the above result we can assume that the model can better predict the surface runoff than the groundwater contribution to stream flow during less precipitation. One reason could be due to the soil data quality and estimation of the curve number at dry moisture condition. Since the SCS curve number is a function of the soil's Permeability, landuse and antecedent soil water conditions that estimation of curve number at dry moisture condition might not be efficient in that watershed.

Parameters	Calibrated value (mm) 1997-2008	Validated Value (mm)	
		2009	2010
Precipitation	938	1034	873
Surface Runoff	245	354	162
Lateral Flow	28	38	37
Return Flow	105	112	96
Percolation to shallow Aquifer	149	158	138
Recharge to Deep Aquifer	7	8	7
Revap. From Shallow Aquifer	40	47	47
Evapotranspiration (ET)	532	442	518
Average Curve Number	80.54	79.54	79.54
Water Yield	378	504	295

Table 5: Different hydrological components for Middle Narmada basin

G. Parameter Sensitivity Analysis:

In this study we have evaluated the relative sensitivity values found in the parameter estimation process. Thirteen parameters were found to be sensitive but the most sensitive parameters were: Soil evaporation compensation factor (ESCO); a change in the value of the ESCO affects all the water balance components, Initial SCS Curve Number II value (CN2);Increased values of CN2 imply an increase in the surface runoff, base flow alpha factor (Alpha_BF) [days], threshold depth of water in the shallow aquifer for "revap" to occur (GW_Revap), channel effective hydraulic conductivity (Ch_k2) [mm/hr] and threshold depth of water in the shallow aquifer for return flow to occur (GWQMN). These sensitive parameters were considered for model calibration. The remaining parameters had no significant effect on streamflow simulations. Changes in their values do not cause significant changes in the model output.

The calibration process using SUFI-2 algorithm gave the final fitted parameters for the basin (Table 6). The final value for CN2, Soil_ AWC includes the amount adjusted during the manual calibration. These final fitted parameter values were incorporated into the SWAT2012 model for validation and further applications.

Sl. No.	Sensitive Parameters	Parameters Description	Lower and Upper Bound	Final Fitted Value
1.	CN2	**Curve Number**	± 20%	-0.05
2.	ALPHA_BF	**Base flow alpha factor**	0 –1	0.19
3.	ESCO	**Soil evaporation compensation factor**	0.8 –1	0.82
4.	GW_DELAY	Ground water Delay (days)	30 – 450	133
5.	SOL_AWC	Water capacity of soil layer	-0.2 – 0.4	0.29
6.	GW_REVAP	**Ground water revapcoefficient**	0 – 0.2	0.07
7.	CH_K2	**Hydraulic conductivity**	5 –130	126.5
8.	GWQMN	**Threshold depth of water**	0 – 2	0.74
9.	SOL_BD	Soil Bulk Density	-0.5 – 0.6	0.41

Table 6: SWAT Flow Sensitive Parameters and Fitted Values after Calibration using SUFI-2

H. Water Balance Ratio:

Table 7 lists the simulated water balance components on an annual average basis for the Middle Narmada basin over calibration and validation period. The results indicated that 46% of the annual precipitation is lost by evapotranspiration in the basin during calibration as compared to 48% during validation period. Surface runoff contributes 65% and 69% of the water yield during the calibration and validation period respectively. Whereas the ground water contributes 28% and 26% of the water yield during calibration and validation period respectively.

Table 7: Water Balance Components on an Annual Average Basis over the Calibration and Validation Periods for Middle Narmada Basin

Period	Year		Precipitation	ET	Sur_Q	Lat_Q	GW_Q	WYLD	PERC
Calibration	**1997-2008**	**mm**	938	532	245	28	105	378	149
		%	100	57	26	3	11	40	16
Validation	**2009**	**mm**	1034	442	354	38	112	504	158
		%	100	43	34	4	11	49	15
	2010	**mm**	873	518	162	37	96	295	138
		%	100	59	19	4	11	34	16

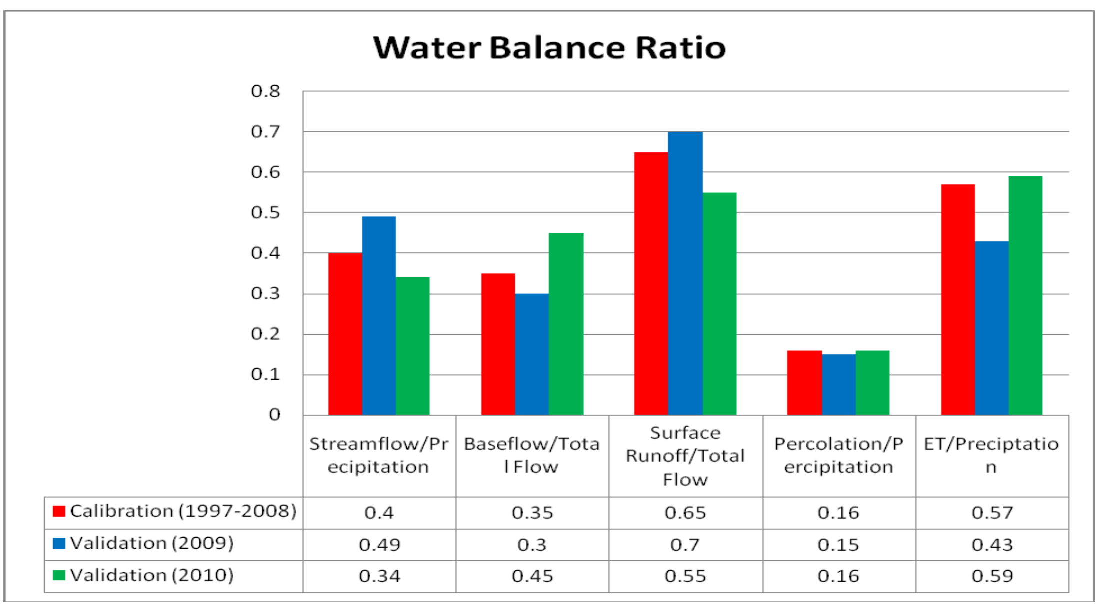


Figure 17: Water Balance Ratio on an Annual Average Basis over the Calibration and Validation Periods for Middle Narmada Basin

4. Conclusion

The SWAT2012 model is successfully calibrated and validated in the Middle Narmada basin using SUFI-2 algorithm. It is applied to the basin for the modeling of the hydrological water balance and surface runoff. The sensitivity analysis of the model to subbasin delineation and HRU definition thresholds showed that the flow is more sensitive to the HRU definition thresholds than subbasin discretization effect. A SUFI-2 algorithm is an effective method but it requires additional iterations as well as the need for the adjustment of the parameter ranges. The hydrological water balance analysis showed that baseflow is an important component of the total discharge within the study area that contributes more than the surface runoff. More than 46% of losses in the basin are through evapotranspiration. Despite data uncertainty, the SWAT model produced good simulation results for daily and monthly time steps. The calibrated model can be used for further analysis of the effect of climate and land use change as well as other different management scenarios on stream flow and of soil erosion.

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