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Research Article

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Modelling of Water resources for sustainable water use in Upper Manair Catchment, Andhra Pradesh

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ABSTRACT

Quantifying the components of the water balance for a watershed is important towards understanding the movement and transformation of water in a watershed or region. Land use changes in a watershed can affect water availability by altering hydrological processes such as infiltration, groundwater recharge, base flow and runoff. Application of watershed models provide accurate estimate of components of water balance thereby availability of water resources. Hence, the watershed model SWAT has been applied to quantify various components of water balance and the impact of land cover change in Upper Manair catchment which comprises parts of the Medak, Nizamabad and Karimnagar districts of Andhra Pradesh, India.

SWAT model was run on upper Manair catchment database for a period of 21 years (1992 to 2012). It apportioned precipitation and irrigation of catchment into different water balance components in which percolation has amounted to 618.72 mm followed by actual evapo-transpiration as 545.1mm and deep aquifer recharge as 464.51 mm. Surface runoff (70.55 mm) and lateral flow (3.92 mm) contributed less. The model was calibrated against observed reservoir volumes using Nash Sutcliffe criteria (0.85). The water balance components of different hydrological response units were simulated which has clearly indicated the impact of land use and soil type on the water yield of the catchment. Paddy accounted for more runoff and cotton and maize contributed less base flow and lateral flow to stream flow.

Keywords: *Water resources, Upper Manair, watershed, Modelling.*

INTRODUCTION

Land and water resources and their management are crucial for improving food security in the country. Although, India has adequate water resources, the factors associated with population growth, increased urbanization and industrialization, energy use, irrigation integrated with advances in agriculture productivity, desertification, global warming and poor water quality have made water a scarce resource in the country.

In addition to water scarcity, land is also limited. The per capita land availability 50 years ago was 0.9 ha and at present, it is only 0.14 ha. This is going to put immense pressure on agricultural production systems and environment and significant advances in agricultural productivity are essential for growing more food grains with less water. Similar situation is prevailing even in the state of Andhra Pradesh also.

It is therefore necessary to understand the issues which are affecting the water availability. Application of models has become an indispensable tool for the understanding of the hydrological processes occurring at the watershed scale as the models provide accurate estimate of components of water balance thereby availability of water resources. As the natural processes are more and more modified by human activities, application of integrated modeling to account for the interaction of practices such as agricultural management, water removals from surface bodies and groundwater etc., has become more and more essential. Various simple models and procedures are available which can quantify the different components of hydrological cycle[1,2]. Hydrological models integrated with geographical information system (GIS) allow quantification of different components of hydrological cycle with high spatial and temporal resolution[3] .

Kamuju.Narasayya *et al.* [4] used SWAT for continuous time scale rainfall-runoff modelling that integrates several years precipitation, GIS knowledge and a hydrology of Burhanpur watershed (about 8527 km^2) covered in inter-states of Madhya Pradesh and Maharashtra, India.

Milad *et al.* [5] used the SWAT model with integrated approach of curve number accounting procedure and plant evapotranspiration method (plant ET method) to simulate runoff in the Roodan watershed (10,570 km^2) of Iran which had low storage soils. It was reported that decrease in depletion coefficient value lead to reduction in runoff and caused SWAT to predict lesser stream flow.

SWAT has been used to quantify the impact of land management practices on the water yield of the watershed with varying soils, land use and management conditions over long period of time for sustainable water resources management in Kothakunta sub-watershed, Andhra Pradesh. Green water loss was also more from paddy field compared to other cultivable crops [6].

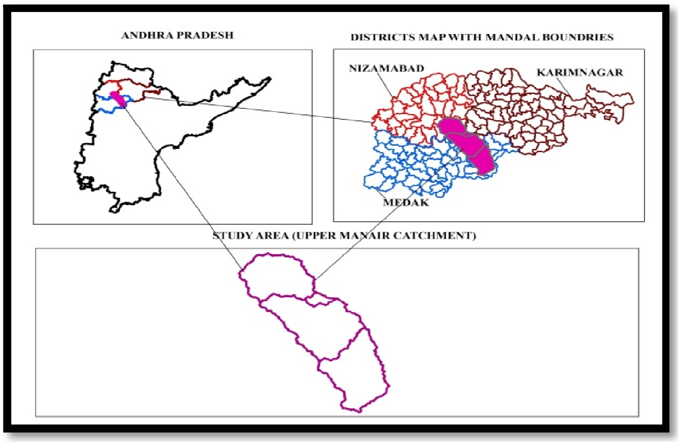
Yan *et al.* [7] used the SWAT model to assess the impact of land use change on watershed stream flow and sediment yield for the Upper Du watershed (8973 km^2) in China. The results indicated that changes in grassland did not show a significant influence on either stream flow or sediment yield.

Hence, Soil and Water Assessment Tool (SWAT) model has been proposed to simulate the possible impact of man made interventions on the quantity of water in the catchment of the upper manair dam.

STUDY AREA

The Upper Manair Catchment (UMC) of Andhra Pradesh was selected for the study. The UMC is located between the latitudes 17.65^0 and 18.50^0 N and longitudes 78.15^0 and 78.85^0 E which comprises parts of the Medak, Nizamabad and Karimnagar districts of Andhra Pradesh. The catchment area is 2, 20,289.48 ha. Two rivers namely Kudlair river of Medak district and Manair river of Nizamabad are flowing through the catchment and contributing the flows to Upper Manair reservoir. The location map of the study area is shown in Fig .1.

Fig. 1. Location map of Upper Manair Catchment, Andhra Pradesh



Physiography

The physiography of the area is undulating having a slope of 1-6%, slightly eroded, and moderately drained. The minimum elevation in the catchment is 342 m and the maximum elevation is 587 m. The mean elevation of catchment is 456.5 m.

Soils

The Upper Manair catchment consists of mainly two types of soils. Clay loam soils occupy an area of 92% in the catchment. Remaining 8% soils are Clay. The physical properties of the soils of the catchment are presented in the following Table .1.

Table. 1 Physical properties of different types of soils of Upper Manair catchment

Soil texture	**Soil layer**	**Layer depth (mm)**	**Bulk density (g cc^{-1})**	**Available water content (%)**	**Hydraulic conductivity (mm/hr)**	**Organic carbon (%)**	**Clay (%)**	**Silt (%)**	**Sand (%)**	**Rock (%)**	**Electrical conductivity (dS m^{-1})**
Clay loam	1	300	1.419	17	3.064	0.6	40	22.76	37.24	50	0.69
	2	1000	1.4651	20	1.5782	0.55	39	26	35	46	0.6
Clay	1	300	1.48	20	2.57	0.7	60	22	18	45	0.33
	2	1000	1.61	25	0.55	0.55	61	22	17	40	0.23

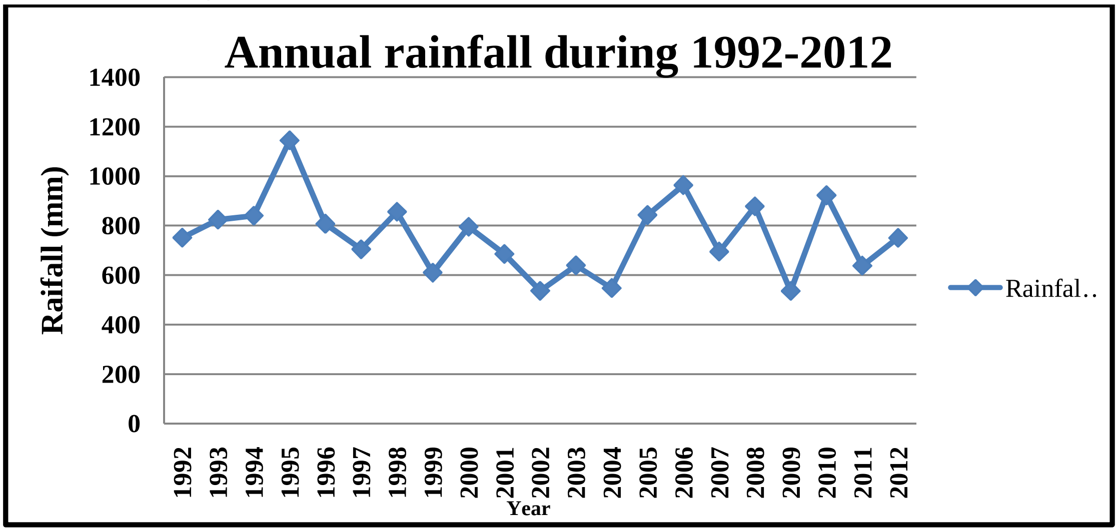
Source: WTC, ANGRAU

Climate

Climate of the study area is semi-arid with distinct summer, winter and rainy seasons. The major amount of rainfall is received during the South-West monsoon. The rainfall distribution is observed as seasonal with more than 75 percent of rainfall received during the South-West monsoon period. North-East monsoon and summer showers constitute remaining 25 percent of rainfall.

The average annual rainfall of 21 years from 1992 to 2012 was 777.8 mm. The highest amount of rainfall was recorded in 1995 as 1143.8 mm and lowest amount of rainfall was recorded during the year 2009 as 536.01mm. The annual rainfall of catchment area for 21 years is shown in Fig.2.

Fig. 2. Annual rainfall of the catchment over the period of 1992-2012



Crops and Cropping Pattern of Study area

The major cropping systems followed in the study area are paddy - paddy, maize-maize, paddy-maize, cotton-maize and maize- sunflower. The major crops grown during *kharif* and *rabi* are paddy, maize and cotton respectively. Sugarcane, sunflower and vegetables are also grown but not in significant area.

The details of different crops grown in the study area are presented in the Table 2.

Table 2: Details of planting time, Leaf Area Index (LAI) and maximum root zone depth of different crops grown in Upper Manair Catchment

Name of the Crop	***Kharif***		LAI	Maximum root zone depth (cm)
	Planting Date	Harvesting Date		
Paddy	II FN of July	II FN of November	3.893	45
Maize	I FN of July	I FN of October	4.348	120
Cotton	II FN of June	I FN of January	5.40	120
Sugarcane	I FN of January	II FN of November	4.5	180
Rabi				
Paddy	I week of December	II FN of April	3.915	45
Maize	I FN of October	I FN of February	3.485	120
Sunflower	I FN of November	II FN of February	4	120

PREPARATION OF MODEL INPUTS

Geospatial Layers

Geospatial layers namely, Digital Elevation Model (DEM), stream network and reservoir, land use and land cover and soil are required for hydrological modeling of the catchment area. The preparation of geospatial layers of the catchment area are explained below.

Digital Elevation Model (DEM)

The Digital Elevation Model was prepared by downloading Cartosat DEM of catchment area from Bhuvan web site provided by NRSC with a resolution of 30 m x 30 m. Two tiles were down loaded and mosaicing and rectification was done. The projection UTM, the spheroid type (WGS 1984) and Datum of WGS 84 and 44 N zone has been applied to DEM. The drainage network /stream network layer was prepared in GIS environment utilizing watershed delineation interface in ARCSWAT.

Land Use / Land Cover Map

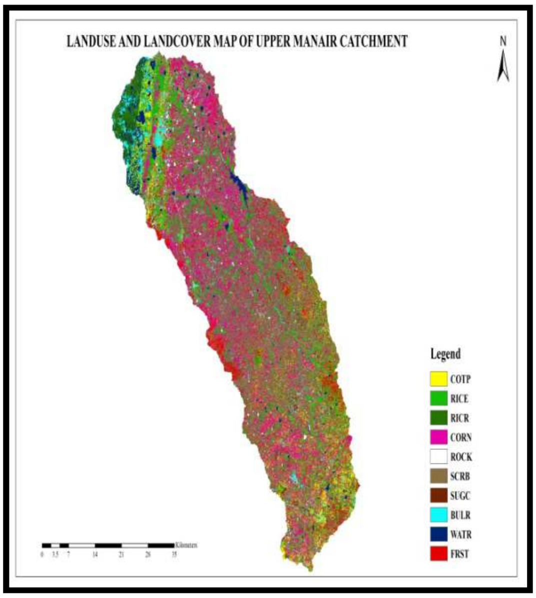
The LULC was prepared for the study area of 2,20,289.5 ha using IRS P_6, LISS III image of December, 2011 and September, 2012. The information from LISS III image and toposheets were utilized for classification of land cover generation of training sets. Ground truth survey was carried out by walking around the field boundaries for two times (*rabi* 2011 *and kharif* 2012) during 2011 to 2012 using GPS.

Major portion of the study area was covered with agricultural crops viz. paddy, maize and cotton. The areas of different land uses of the study area are presented in percentage in Table 3.

Table. 3. Land use pattern in Upper Manair Catchment

S.No.	Land use	Area (ha)	Percentage (%)
1	Cotton	21069.9	9.57
2	Rice (*kharif)*	44170.6	20.06
3	Rice *(rabi)*	9479.8	4.31
4	Corn	53978.3	24.52
5	Rock	4331.0	1.97
6	Built up land	8641.0	3.92
7	Sugar cane	7619.6	3.46
8	Water bodies	7197.7	3.27
9	Forest	19236.2	8.74
10	Range lands	44448.7	20.19

Fig. 3. Land use and land cover map of Upper Manair Catchment

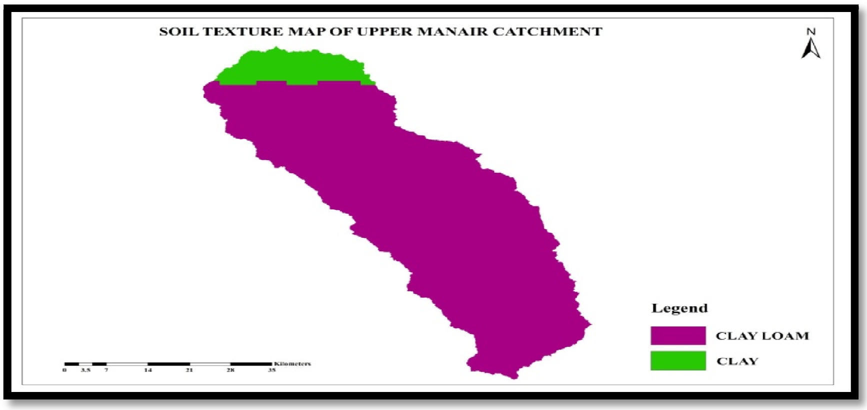


Note: COTP- Single crop cotton, RICE- Single crop paddy, RICR- Double crop paddy, CORN- Double crop maize, ROCK- Rock land, SCRB- Scrub land, SUGC- Sugarcane BULR- Built up land, WATR- Water bodies, FRST- Forest land

Soil Texture Map

The soil map (1.250,000) developed by NBSS & LUP has been taken as reference map and clipped to the catchment area. The soil textural classes were identified. One is clay loam soil and another one is clay soil. In addition to that the soil map prepared by SWAT group for India was also considered to ascertain the types of soils. The generated soil map is shown in Fig. 4. The properties of soils were finalized from the information collected through secondary sources. The information was collected from RARS, Jagtial, ICRISAT and literature of study area respectively.

Fig. 4. Soil texture map of Upper Manair Catchment



SWAT MODEL

SWAT allows a number of physical processes to be simulated in a watershed. The watershed may be partitioned into a number of sub watersheds or sub basins. The use of sub basins in a simulation is particularly beneficial when different areas of the watershed are dominated by land uses or soils dissimilar enough in properties to impact hydrology. By partitioning the watershed into subbasins, the user is able to reference different areas of the watershed to one another spatially. Input information for each subbasin is grouped or organized into the following categories, climate, hydrological response units or HRU, ponds/wetlands, groundwater and the main channel or reach, draining the subbasin.

Water balance is the driving force behind everything that happens in the watershed. Simulation of the hydrology of a watershed can be separated into two major divisions. The first division is the land phase of the hydrologic cycle which can control the amount of water, sediment, nutrient and pesticide loadings to the main channel in each subbasin. The second division is the water or routing phase of the hydrologic cycle which can be defined as the movement of water, sediments, etc. through the channel network of the watershed to the outlet.

Watershed Delineation

The DEM has been prepared by downloading from BHUVAN website. The Arc SWAT interface automatically generated stream network, flow direction and accumulation by taking into consideration the elevation values of DEM and masked area on the DEM. The outlet point needs to be identified as the entire watershed contributes flow to the specified outlet. The outlet points have been added based on the flow from Kudlair river and Palvancha vagu (Manair river) reaching to Upper Manair reservoir. The delineation of watershed was completed based on the added outlet points. The reservoir point has also been set at the outlet of the watershed.

Hydrological response units

Hydrologic response units are lumped land areas within the subbasin that are comprised of unique land cover, soil and management combinations. For generation of hydrological response units in the watershed area, the land use land cover change, soil groups present in the whole watershed area, slope, aspect and elevation are necessary. In the Upper Manair catchment 100 HRUs are created by overlaying land use, soil and slope maps of the study area.

Database

Custom weather database which includes all the climatic parameters of the catchment area was needed as input to obtain accurate estimate of the water yield of the catchment. The inputs like precipitation (mm), temperature (^{0}C), solar radiation (MJm^{-2}d^{-1}), relative humidity (%) and wind speed (m^{2}sec^{-1}) were prepared using DBase IV spread sheet since SWAT accepts the data in DBase IV format only.

The different physical properties of soils in study area are presented in the Table .1 which were utilized in estimating infiltration, percolation and lateral flow components of water balance .

Crop data file was formulated with information on various parameters namely, crop coefficient values (K_c), Leaf Area Index (LAI), optimum temperature, targeted biomass, harvest index, etc which were given accordingly as per crops grown in the study area. The developed crop management files are appended to the data base. The information pertaining to the beginning and ending of the growing season, timing of tillage operations and irrigation applications and timing and amount of fertilizers are prepared in a database and used as input to simulate the impact of management practices on water and sediment yield. Paddy and maize were grown in both seasons. Cultivar parameters were derived from local expertise. Planting and harvesting dates were provided on local practice to obtain the highest yield in each location throughout the study area. Irrigation amount was given based on farmer's method and withdrawn from deep aquifer of catchment. Crops were fertilized with inorganic fertilizers in crop-type specific proportions and compositions adopted by the farmer's of the region.

APPLICATION OF SWAT MODEL:

A base SWAT model has been created with the dataset of Upper Manair catchment and simulated total water yield, reservoir levels, reservoir discharge and reservoir volume for the period 1992 to 2012. It was also calibrated then validated to obtain accurate simulation since calibration and validation are important processes for any simulation model to understand its certainties, confidence levels and limitations.

Calibration and validation of model

Utilizing output from sensitivity analysis, the model was calibrated and validated against the measured reservoir volumes of 12 years from 2001 to 2012. Data pertaining to year 2006 to 2012 has been used for calibration and the rest for validation. Daily reservoir volumes simulated by the model is shown in the time series curve in Fig. 5. The model has been calibrated and validated for daily reservoir volume. The period from 2006 to 2012 has been chosen as the calibration period and 2001 to 2005 is taken as the validation period for the daily time step analysis. The simulated reservoir volumes match well with the observed values. The graph has clearly shown that the simulated values were on par with the observed values (Fig. 6). The results obtained in the present study were in good agreement with R^2 =0.85. The Nash-Sutcliffe efficiency (NSE) criteria was also used to calibrate and validate the model. The range of NSE varies from $-\infty$ to 1. However, if NSE is > 0.5 for monthly stream flow data, it indicates that model is performing satisfactorily[10]. The computed NSE was 0.85. Out of the four reservoir simulation options, average annual reservoir outflow option showed over estimation with daily data. The results indicate that the target release approach using non-specific or specific target release approach in the SWAT model can effectively simulate reservoir volumes with the limited information of reservoir. Hakkwan and Parajuli [8] also confirmed the same through simulation of reservoir volumes in Grenada Lake Reservoir watershed (4,500 km^2) within the Yazoo River Basin since reservoir operation has control on out flow volume.

Fig. 5. Simulated Upper Manair reservoir volumes

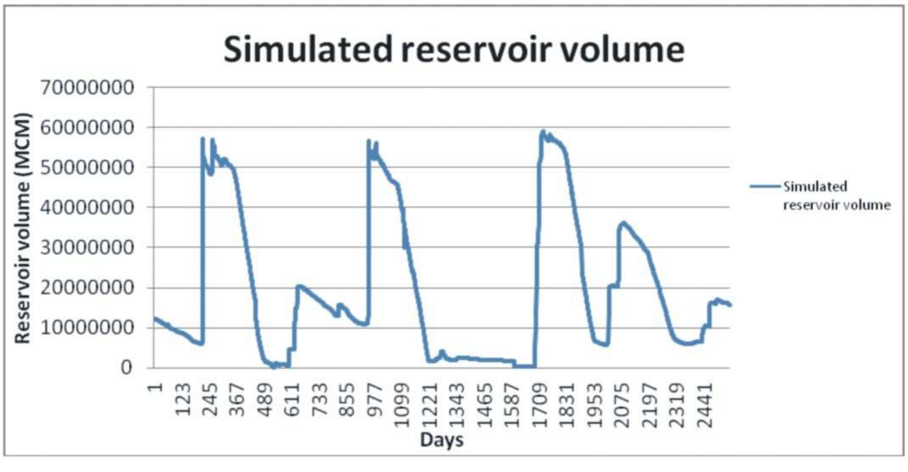
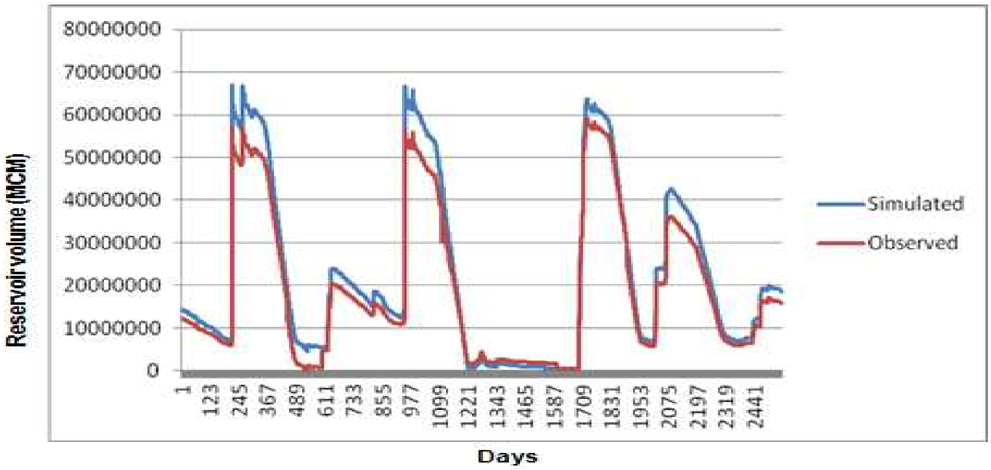


Fig. 6. Comparison of observed and simulated reservoir volumes



RESULTS OF THE MODEL

The model provided detailed output on different components of water balance like rainfall, surface runoff, lateral flow, water yield, soil water content and actual ET and crop water requirements of the cropping system in the catchment.

Average Monthly Basin values

The monthly basin values were presented in the Table 4. The hydrological parameters such as percolation, surface flow, ground water flow indicated good relationship with precipitation. Actual evapotranspiration values were estimated based on climatic data, available water content in the root zone and properties of soil. It was also dependent on number of crops grown in the different seasons of the year and amount of water applied through irrigation. Generally, ET will be more during April to August in a year. However, ET was more even during the months of September to November. This is mainly due to the *Rabi* crops namely, Rice, Maize and Sugarcane grown in the catchment.

The model simulated surface runoff using curve number technique and lateral flow through soil by storage routing technique. Whenever there is rainfall, surface runoff and lateral flow have contributed to the stream flow. The maximum amount of surface runoff simulated was 29.68 mm in the month of August that coincided with the highest amount of rainfall recorded during the month. Soil moisture values varied from 176.66 mm to 323.81 mm.

Table 4. Average Monthly Basin values of different compo nents of Water Balance

Month	Rainfall (mm)	Surface runoff (mm)	Lateral flow (mm)	Water yield (mm)	Soil water (mm)	Actual ET (mm)
January	10.57	0.71	0.37	4.42	260.72	39.64
February	4.80	0.06	0.31	3.09	235.54	39.88
March	17.42	0.26	0.28	2.65	222.71	40.10
April	14.35	0.11	0.23	1.64	185.23	40.02
May	13.98	0.13	0.20	0.97	176.66	46.74
June	83.20	1.02	0.18	1.21	243.99	42.40
July	183.57	12.53	0.24	12.80	320.08	48.10
August	207.94	29.68	0.38	32.05	323.81	49.46
September	142.77	17.11	0.45	21.76	316.63	54.67
October	79.74	8.17	0.48	14.00	297.92	60.14
November	17.14	0.68	0.43	6.02	286.65	46.58
December	2.46	0.08	0.40	4.80	274.27	38.39

Average Annual Basin Values

In order to present the order of magnitude of these allocations of precipitation in to different components of water balance, the annual average basin values were presented in the Table.5. The average annual precipitation was 777.8 mm. This precipitation was apportioned to water balance components in which percolation has accounted high followed by evapotranspiration (545.1 mm) and total aquifer recharge. Surface runoff and lateral flow contributed less to the flow. The average annual ET of the basin is around 70% of the precipitation. Thanapakpawin *et al.* [11] also reported that simulated average annual evapotranspiration was corresponding to 74% of basin-wide estimated precipitation and it can range between 70 – 75% for agricultural based watersheds.

Table 5. Average Annual Basin Values of different components of Water balance

Process	Average Annual Value (mm)
Precipitation	777.8
Surface runoff	70.55
Lateral flow through Soil	3.92
Groundwater (shallow aquifer)	31.42
Capillary rise	25.38
Deep aquifer recharge	464.51
Total water yield	105.34
Percolation out of Soil	618.72
Actual Evapotranspiration	545.1

Water yield from different HRUs

HRU is a combination of land use, soil type, and slope. Based on HRU definition, the prominent HRUs were identified in a watershed. The water balance components of different HRUs were simulated and presented in the Table 6. Water comprised 3.27% area in the watershed. Evaporation was the major process taking place from all the open water bodies in the catchment.

Next important HRU with reference to consumption of water was paddy. Paddy occupies an area of 24.37% (Paddy *Kharif*, 20.06% and Paddy *Rabi*, 4.31%) in the watershed. The water balance components for different land uses namely paddy, corn, cotton, sugarcane, scrubland, forest and built up land have been presented in the Table 6. The above results indicate that the model has simulated very well the impact of soil type and land use on the yield of water.

The surface runoff, ground water contribution to stream flow was very high from sugar cane compared to other crops and non-cultivable area**.** ET was high in clay soils compared to clay loam soils in the watershed for paddy, cotton and maize. However, the ET was little less in clay soils (712.64 mm) compared to clay loam soils (726.88 mm) for sugarcane. The actual evapotranspiration from rice fields was 784.6 mm due to ET from rice and evaporation from the stagnant water. There was a little change in the ET due to variation with the soil type in the rice fields. The evapotranspiration ranged between 748.82 to 784.6 mm for the paddy fields which was shown in Fig. 7. The ET of Cotton and the Maize ranged from 712.40 to 758.07 mm with more water use efficiency due to deep rooted system. The green water loss (Evapotranspiration) is less for maize and cotton.

Similarly, the surface runoff was more from the paddy fields where it ranged from 114.85 to 401.01mm for different soil types. The formation of impervious layer due to puddling in the paddy field lead to more runoff by arresting infiltration and percolation into the soil. Whereas it was more from sugar cane with clay soils. In synchronization with paddy fields, the sugar cane also showed high surface runoff (413.5 mm) from clay soils[9]. Forest area accounts for 8.74% area of the total watershed area and it showed the significant role in generating surface runoff ranged from 25.39 to 161.25 mm. Highest runoff was simulated in the clay soils of Scrub land.

Ground water contribution to the stream flow was the prime component which sustains the water availability in the watershed. It was poor for scrub land, built up area and rock land irrespective of soil type. It was more for sugar cane followed by paddy and ranged from 385.85 to 519.26 mm. It was mainly due to percolation from stagnant water in the field. The contribution to stream flow was less from maize and cotton and ranged from 7.28 to 12.26 mm. The soil types which respond more for ground water recharge were in order of clay loam and clay respectively. It mainly depends on the saturated hydraulic conductivity of different layers of soil.

Influence of soil type on water balance components

In the paddy crop, the evapotranspiration was high followed by ground water contribution to stream flow (GWQ) in clay loam (Fig. 8). Similar trend was observed for cotton, maize and sugar cane also with high contribution from ET (Fig. 9). However, ET was more from clay soils for cotton, maize and paddy except sugarcane. In the maize field, clay soil showed significant effect on water balance where the available moisture content and evapotranspiration rate was high compared to clay loam soils (Fig. 10). In the cotton crop, clay soil showed significantly high values of water balance with more available water content and ET, but poor in the GWQ. Surface runoff recorded high for sugar cane in clay soil (Fig. 11).

Table 6. Water balance components of different HRUs

S. No	Land use	Type of soil	Available water content (mm)	Surface Runoff (mm)	Ground water contribution to stream flow (mm)	Actual Evapo - transpiration (mm)
1	Paddy	Clay loam	175	114.85	482.54	748.82
		Clay	203.58	401.01	385.86	784.60
2	Double crop Maize	Clay loam	175.00	61.38	12.26	712.40
		Clay	203.58	218.03	10.41	758.07
3	Cotton	Clay loam	175.00	86.29	2.21	714.47
		Clay	203.58	188.19	7.28	716.19
4	Sugarcane	Clay loam	175.00	96.85	519.26	726.88
		Clay	203.58	413.5	396.73	712.64
5	Built up land	Clay loam	175.00	78.26	2.35	422. 60
		Clay	203.58	187.03	0.2	423.22
6	Scrub land	Clay loam	175.00	21.84	3.74	397.89
		Clay	203.58	140.66	0.24	407.13
7	Forest	Clay loam	175.00	25.39	7.59	277.56
		Clay	203.58	161.25	3.29	307.25
8	Rock	Clay loam	175.00	17.69	3.26	424.63
		Clay	203.58	136.92	0.24	422.82

Fig. 7. Water Balance components of different crops in the watershed

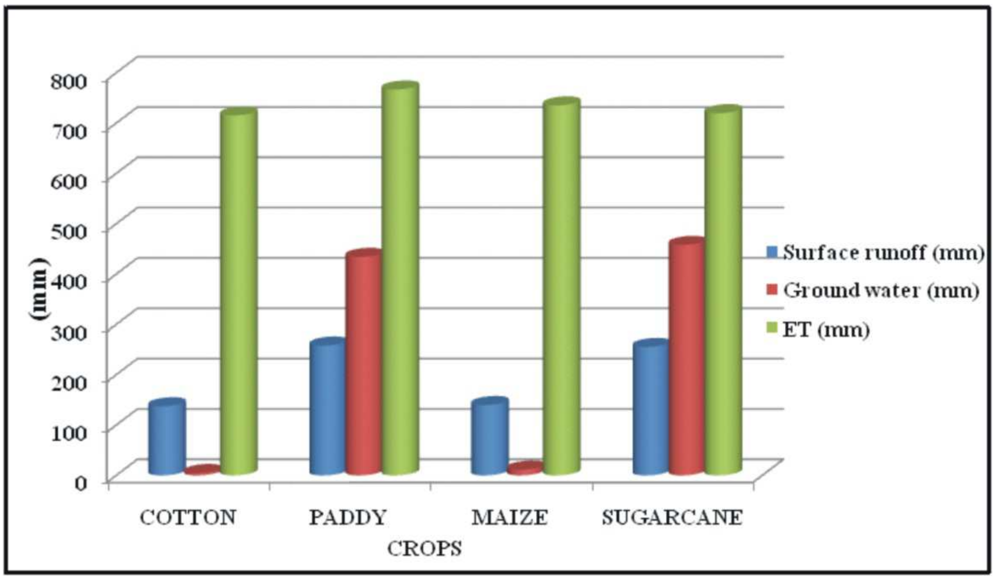


Fig. 8. Water Balance components for different soil types in Paddy

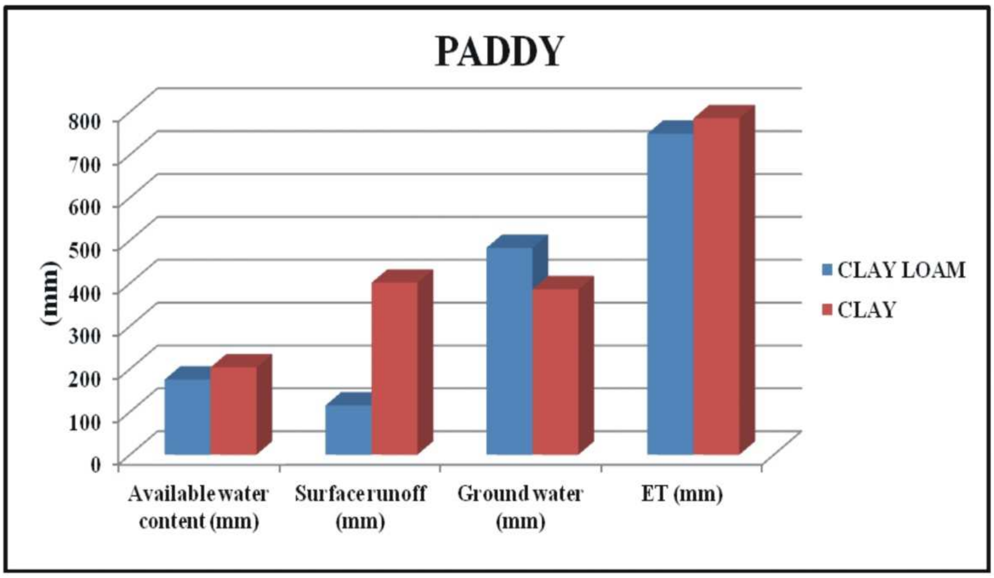


Fig. 9. Water Balance components for different soil types in Sugar cane

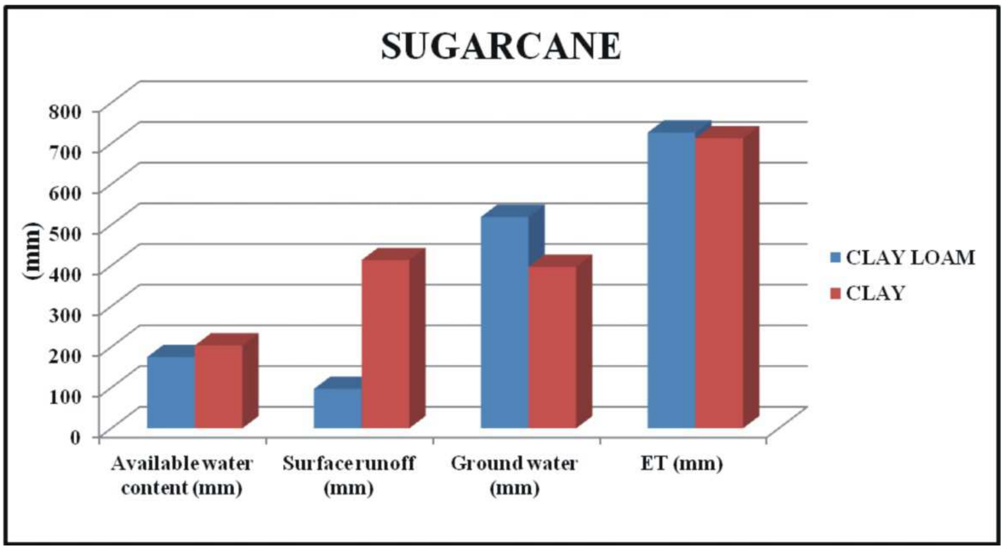


Fig. 10. Water Balance components for different soil types in Maize crop

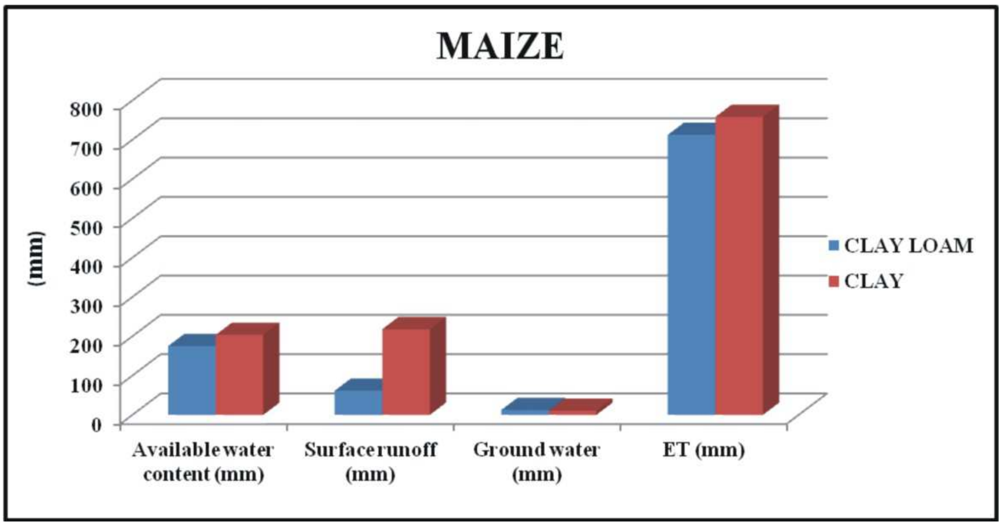
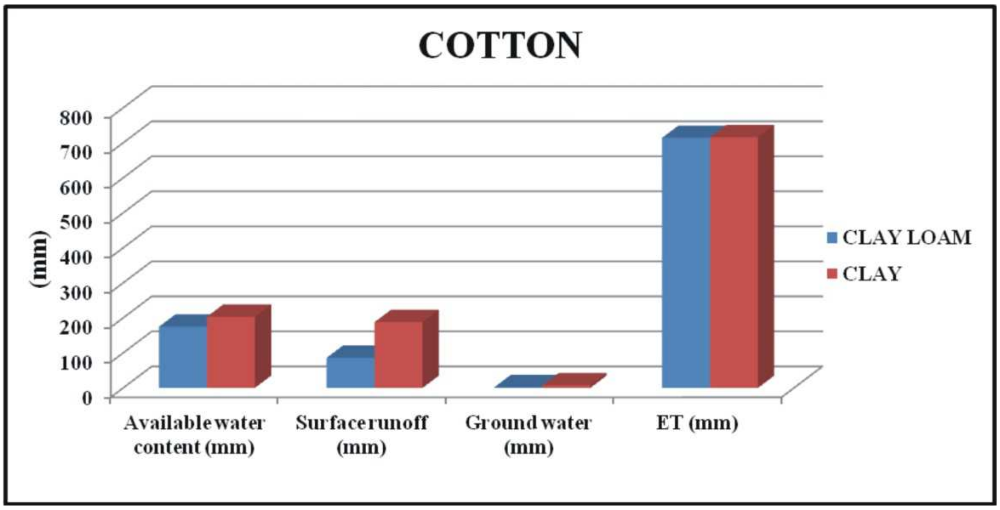


Fig. 11. Water Balance components for different soil types in Cotton



CONCLUSIONS

SWAT model can be applied effectively for upper Manair catchment and it has modeled very accurately the impact of land use, soil type and slope on water yield of the catchment. Quantification of different components of water balance will help in deciding the cropping pattern and irrigation scheduling which in turn increase water productivity. Long term cultivation of paddy with ground water resources lead to aquifer depletion and ground water pollution. Reducing area under paddy cultivation and allocating the reduced area to irrigated dry crops will lead to sustainability of water resources. However, positive effects of rice paddy fields on runoff should be considered in making decisions about the reduction of rice cultivation.

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