Impact of Change in Land Use Land Cover on Water Resources in Gundlakamma Sub Basin

N. Hari1*, A. Mani2, H. V. Hema Kumar3, V. Srinivasa Rao4 and L. Edukondalu5

1Department of Agricultural Engineering, PJTSAU, Hyderabad, India.
2Dr NTR College of Agricultural Engineering, ANGRAU, Bapatla, India.
3Department of Soil and Water Engineering, Dr NTR College of Agricultural Engineering, ANGRAU, Bapatla, India.
4Department of Statistics and Computer Applications, Agricultural College, ANGRAU, Bapatla, India.
5Department of Agricultural Processing, Dr NTR College of Agricultural Engineering, ANGRAU, Bapatla, India.

Authors’ contributions

This work was carried out in collaboration among all authors. Author NH designed the study, carried SWAT model, wrote the protocol and wrote the first draft of the manuscript. Author AM guiding and helped in draft. Author HVHK helped in drafting of the paper. Author VSR helped in statistical analysis. Author LE helped in literature searching. All authors read and approved the final manuscript.

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ABSTRACT

The present study was conducted to investigate the impact of land use cover change on water resources availability in Gundlakamma Subbasin. The Gundlakamma subbasin is predominantly agricultural based and Gundlakamma is a seasonal river. Hence, a study has been conducted to simulate the availability of water resources in the subbasin using SWAT (Soil and Water Assessment Tool) model. The database was generated like DEM, soil map and land use/cover using the secondary data and field survey. The SWAT model was calibrated three years (2010-2012) and validated with four years (2013-2016) with the observed discharges from reservoir outflow. The values of NSE and $R^2$ was found as 0.79 and 0.87 during calibration, 0.65 and 0.72,

*Corresponding author: E-mail: hariagengg2022@gmail.com;
respectively during validation. The modelled values showed reasonably good agreement with the observed values of reservoir outflow, both during calibration and validation periods. The reservoir outflow in the subbasin was quantified under the change land use conditions.

Keywords: Water resources; land use land cover; SWAT; reservoir flow; parameters.

1. INTRODUCTION

Water is a finite resource and its availability is declining with each passing day. Agriculture sector, the largest consumer of water i.e., 82.8% (World Water Assessment Programme (UNESCO WWAP), is facing competition from other sectors due to the ever increasing demands of the burgeoning population and accelerated pace of urbanization and industrialization in the country. It is expected that reduction in the average size of land holding, declining per capita water availability, deterioration of water quality, etc. will seriously affect the sustainable use of water resources and will make it difficult to accomplish the target of producing 345 Mt in 2030 and 494 Mt in 2050 AD [1]. With growing scarcity and increasing inter-sectoral competition for water, the need for efficient and sustainable management of water has also become more important. Finding ways to meet the competing demands, while also achieving positive economic and environmental outcomes, requires the aid of modelling tools to analyze the impact of land use and land cover change scenarios [2,3].

Hydrological modelling studies in basins with spatial and temporal variability are important because they help to understand processes that control water movement and the likely impacts on water quantity and quality. A river basin or watershed is an area over which various hydrologic processes such as precipitation, snowmelt, interception, evapotranspiration, infiltration, surface runoff, and sub-surface flow are integrated. Assessment of water resources in a basin or catchment is very much essential to understand the quality and quantity of the water resources present in the basin. Hydrological model is a tool to evaluate the dynamic availability of water resources from time to time for the sustainability of the basin or catchment. Impact assessments on water resources using hydrological models are essential for a basin/subbasin level planning and management of water resources for its sustainability.

Hydrological modeling involves formulating the mathematical models to represent these hydrologic processes as well as the interaction between them. The inter-relationship of soil, water, climate, and land use are considered and represented through mathematical abstraction [4] in hydrological modeling. This can be challenging because it involves highly nonlinear processes, complex interactions and high spatial variability at basin scale. Starting from the mid of the nineteenth century, the evolution of hydrological modeling is continuing with the development of understanding the physical processes, computational efforts and data retrieving facilities. With the advent of Geographic Information System (GIS), it has become easier to handle a large amount of data that conceptual distributed hydrological models demand, thus, enabling process simulations with greater physical foundation. SWAT (Soil and Water Assessment Tool) is one such conceptual model, semi-distributed and continuous model, and was developed to predict effects of land covers and soil managements on water and sediment production as well as water quality [5-7] and it is predominantly used for agricultural watersheds. Among the available models, SWAT is one of the comprehensive models that is widely used and highly recommended by the researchers because of its various advantages and capabilities than the others models [8]. SWAT has been calibrated and applied in hydrological simulation for several basins worldwide by several authors [9-12].

Land use and land cover (LULC) change is one of the stressors that significantly affect hydrological balance and then aggravate water quantity issues [13]. Hydrological processes such as infiltration, groundwater recharge, base flow and surface runoff are influenced by land use changes in a catchment. LULC modification such as changes in vegetation cover alter surface roughness and leaf area index (LAI) that can lead to disturbance in surface energy balance and evapotranspiration (ET) [14]. Hence, SWAT model was selected to simulate the water resources in the present study. The changes in energy balance and ET may significantly affect the timing and magnitude of evaporative losses to the atmosphere and the amount of water yield that governs soil moisture content, runoff and
base flow patterns of regional hydrologic responses. Hence these disturbance in hydrological balance lead to change in runoff rate, volume and intensity and frequency of floods [15,16].

The present study is aimed at calibration and validation of SWAT for simulating reservoir outflow and effect of land use land cover on water resources in the Gundlakamma subbasin.

2. MATERIALS AND METHODS

2.1 Description of Study Area

The study area was a part of Gundlakamma river basin and is predominantly agricultural based. The Gundlakamma river is a seasonal river and its rises in the Nallamalla Range of the Eastern Ghats. After passing the mountains, it enters the plains of Andhra Pradesh, India. It is located between the latitudes of 15° 50' 59.166" -15° 29' 27.166" N and 79° 38' 7.794" -80° 11' 24.858" E (Fig. 1). The Gundlakamma subbasin comprises of Thurupu vagu, Pasapugalla vagu, Nalla vagu, Kalla vagu, Dornapu vagu and Chillakaleru tributaries (Fig. 2) which are contributes to Gundlakamma river.

2.2 Soil and Water Assessment Tool (SWAT)

SWAT is a river basin model, developed by the United States Department of Agriculture (USDA)-Agricultural Research Service, to simulate the quality and quantity of water resources and predict the impact of land use, land management practices on water resources [17]. SWAT is a continues time model that operates on a daily time step at basin scale. This model can be applied in watersheds with area ranging from a few hundreds of km² to several thousands of km².

It allows a number of different physical processes to be simulated in a watershed. The simulated processes include surface runoff, infiltration, evaporation, plant water uptake, lateral flow and percolation to shallow and deep aquifers. In this model, the watershed is first divided in to a number of sub-watersheds / subbasin based on topographic criteria, and then further discretization into a Hydrologic Response Unit (HRU) based on land use, soil type and slope classes. Areas with the same topographic characteristics, soil type, land use and management form a hydrologic response unit (HRU), a basic computational unit assumed to be homogeneous in hydrologic response to land use/land cover change.

In SWAT, surface runoff is estimated by a modified Soil Conservation Service (SCS) curve number equation using daily precipitation data based on soil hydrologic group, LULC characteristics and antecedent soil moisture. Despite the empirical nature, this approach has been proved to be successful for many applications and for a wide variety of hydrologic conditions [18]. The runoff from each subbasin is routed through the stream network to the main basin outlet [5] to obtain total runoff for the watershed. The SWAT uses storage routing technique to predict flow through each soil layer in the root zone. Percolation is modeled with a layered storage routing technique [19]. Infiltration is estimated using Green-Ampt equation. Percolation occurs when the field capacity of soil layers is exceeded and layer below is not saturated. The flow rate is governed by the saturated conductivity of the soil layer.

Potential Evapotranspiration is computed using the modified Penman Monteith method which requires the climatic input of daily maximum and minimum temperature data. The daily value of the leaf area index is used to partition the PET into potential soil evaporation and potential plant transpiration. Lateral subsurface flow is calculated simultaneously with redistribution. Finally, surface runoff is be computed by subtracting infiltration from rainfall.

A brief description of some of the main components of the model is provided in this study, more detailed descriptions can be found in Nietsch et al. [8]. The soil water balance equation is the basis of the hydrological model which is given below (equation 1).

\[
SW_t = SW_0 + (R_{day} - Q_{sur} - E_a - W_{seep} - Q_{gw}) \quad (1)
\]

Where,

- \( SW_t \) = Final soil water content (mm)
- \( t \) = Time (days)
- \( SW_0 \) = Initial soil water content on day (mm)
- \( R_{day} \) = Amount of precipitation (mm)
- \( Q_{sur} \) = Amount of surface runoff (mm)
- \( E_a \) = Amount of evapotranspiration (mm)
- \( W_{seep} \) = Amount of water entering the vadose zone (mm)
- \( Q_{gw} \) = Amount of return flow (mm)
Fig. 1. Location map of Gundlakamma subbasin

Fig. 2. Location map of tributaries of Gundlakamma subbasin
2.3 Development of Data Base for the Study Area

2.3.1 Weather

Custom weather database which includes all the climatic parameters of the study area is needed as input to obtain accurate estimate of the water yield of the catchment. The inputs like precipitation (mm), temperature (°C), solar radiation (MJm\(^{-2}\)d\(^{-1}\)), relative humidity (%) and wind speed (m sec\(^{-1}\)) were prepared using DBase IV spread sheet since SWAT accepts the data in DBase IV format only. The daily precipitation, temperature (maximum and minimum), solar radiation, relative humidity, and wind speed data were collected from Agricultural Research Station, Darsi (ANGRAU) from 1988-2017.

2.3.2 Data on Groundwater for Gundlakamma subbasin

SWAT partitions groundwater into two aquifer systems: a shallow, unconfined aquifer which contributes return flow to streams within the watershed, and deep, confined aquifer which contributes no return flow to streams inside the watershed. The properties governing water into and out of the aquifer were initialized in the groundwater input file. The data were collected from piezometers and central ground water board of Prakasam district of 2008 to 2016. The groundwater during pre monsoon season ranged between 1.09 m and 8.94 m below ground level and shallow water level of less than 2 m below ground was observed in the north eastern parts of the study area, whereas water level of more than 5 m below ground level was noticed in western parts of the study area [20].

2.3.3 Discharge data of inlet point

The discharge contribution from outside the basin can be considered by adding inlet point in the basin. The inlet discharge can be directly added to the subbasin without simulation of water yield. The subbasin has a reservoir which contributes the water resources from the Gundlakamma river basin and the water which is supplied to different sectors for that purpose the inlet discharge was added. The inlet discharge data was available from 01/01/2009 to 31/12/2016 at Central Water Commission (CWC) gauge, Marella of Prakasam district of Andhra Pradesh. The location of the gauge point was 15°52' 58'' N, 79°54' 36'' E (Fig.1.) The inlet data was collected from the Office of the Chief Engineer, Krishna & Godavari basin Organization, Central Water Commission, Krishna Godavari Bhavan, Hyderabad.

2.3.4 Details of Gundlakamma reservoir

Reservoirs are impoundments located on the main channel network of the subbasin. Reservoir receives loadings from all upstream subbasins. The inflow and outflow from the reservoir and sedimentation in the reservoir can be simulated using SWAT model.

Kandula Obula Reddy Gundlakamma Reservoir Project is formed across Gundlakamma river near Chinnamallavaram Village of Maddipadu Mandal in Prakasam District of Andhra Pradesh at 79°59'15'' E, 15°39'30'' N (Fig.1). It is envisaged to utilize 12.845 TMC (one thousand million cubic feet) of water to provide irrigation facilities to 25,239.43 ha in Kharif and 3,239.13 ha in Rabi season in 6 Mandals of Prasakam District besides providing drinking water facility to 2.56 Lakh population in 43 villages enroute canals and Ongole town. The mean monthly reservoir outflow was collected from Office of Chief Engineer, Ongole from 01/01/2008 to 31/12/2016 and used for calibration and validation of the SWAT model.

2.4 Preparation of Thematic Maps of Study Area

The basic maps required for the Arc-SWAT 2012.10_3.19 is compatible with Arc-GIS 10.3.1, build 4959 include digital elevation model, soil, LULC and drainage network (stream lines). In addition, the SWAT interface requires the designation of land use, soil, weather as well as the simulation period to ensure a successful simulation. Universal Transverse Mercator (UTM) projections corresponding to zone 44 N was used as the projection system for all the thematic maps. To create a SWAT dataset, the interface needs access to ArcGIS compatible raster and vector datasets (shape files and feature classes) and database files which provide certain types of information about the watershed.

2.4.1 Delineation of watershed

The Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) with a resolution of 30 m x 30 m was downloaded from USGS (United States of Geological Survey) https://earthexplorer.usgs.gov/. Two tiles were
downloaded and mosaicking and rectification was done. The DEM of the study area was loaded through ArcGIS environment and mask area which is the area of interest was also created to generate stream network. The ArcSWAT interface automatically generated stream and drainage network by taking into consideration elevation values of DEM, mask and pre-defined stream network generated from toposheets. The outlet point needs to be identified as the entire watershed contributes flow to the specified outlet. The delineation of watershed was completed based on outlet point of each subbasin and there are 8 subbasin in the study area in Fig.1. The delineated watershed and stream network is depicted in Fig. 2. The area of the subbasin was 1330.791 km².

2.4.2 Land use / land cover map

The LULC map was prepared for the study area using IRS (Indian Remote Sensing Satellite) P6, LISS III (Linear Imaging Self-Scanner) images downloaded from https://bhuvan-app3.nrsc.gov.in/data/download/index.php of December, 2011 and September, 2012 and December, 2014 and September, 2015. 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 during 2011 to 2012 (rabi 2011 and kharif 2012) using Global Positioning System (GPS).

Major portion (55%) of the study area was covered with agricultural crops viz., paddy during rabi and kharif. Kharif contains chillies, cotton and redgram. Rabi contains tobacco and bengalgram. Plantation trees were also present in some parts of the study area. The study area has more current fallow land (24.79%) and scrubland (9.54%) followed by less forest area (0.34%). The different land uses of the study area were shown in Fig. 3 (a) and 3 (b).

2.4.3 Soil Texture Map

The soil map (1: 250,000) developed by NBSS & LUP https://www.nbsslup.in/ has been taken as reference map and clipped to the catchment area. The soil textural classes were identified. In addition to that the soil map prepared by SWAT group for India was also considered to ascertain the types of soils. The different types of the soils in study area (Fig. 4) were clay, clay loam and sandy soils with 51.11%, 46.26% and 2.63% area representation respectively.

The soil properties such as soil texture, available water content, hydraulic conductivity and bulk density for different layers were obtained from literature for the study area (Fig. 4) [21].

![Fig. 3(a): Land use land cover map of Gundlakamma subbasin during 2011-12](image1)

![Fig. 3(b): Land use land cover map of Gundlakamma subbasin during 2014-15](image2)
2.4.4 Slope map

From the DEM slope map was generated and four classes were specified (Table 1) for the study area. The area under more than 8% was 31.12%. The area between 6-8% slopes was 17.25%.

2.4.5 Delineation of Hydrological response units (HRU)

The HRU’s are used to describe spatial heterogeneity in terms of land cover, soil type and slope class within a watershed. One or more unique land use/soil/slope contributions (Hydrologic Response Units or HRU’s) can be created for each subbasin by overlaying land use, soil and slope maps. In the Gundlakamma subbasin, 192 HRUs were created by overlaying land use, soil and slope maps of the study area.

2.4.6 Agricultural Management Practices

SWAT requires management operations on agricultural land to model the impact of cultivation practices on soil, hydrology and nutrients loading [8]. It allows management operations to be scheduled by day (fixed dates) or by fraction of potential heat units [8]. For the Gundlakamma subbasin, the scheduling of management operations (cultivation operation) was specified by predefined days.

Crop data file was formulated with information on various parameters namely, Leaf Area Index, optimum temperature, targeted biomass, harvest index, etc which were given accordingly as per crops grown in the study area. The developed crop management files were appended to the data base. The information pertaining to the beginning and ending of the growing season, timing of tillage operations, irrigation applications and timing and amount of fertilizers are included in a database and used as input to simulate the impact of management practices on water. Paddy and maize were grown in both seasons. Cultivar parameters were derived from local expertise. The data were collected from formers field and secondary source.

2.4.7 Simulation with SWAT model

The base model has been developed for the period during 2008 to 2016 and simulated the water yield and calibrated to produce accurate simulation.

2.4.8 Calibration of SWAT model

The SWAT Calibration Uncertainty Programs (SWAT-CUP) is an interface that connects with SWAT models. SWAT-CUP performs sensitivity analysis, calibration, validation and uncertainty analysis in hydrological models. SWAT-CUP consists of algorithms that can solve the different problems that the SWAT model needs for calibration and verification. The algorithms used in the SWAT-CUP program are sequential uncertainty fitting 2 (SUFI-2), particle swarm optimization (PSO), generalized likelihood uncertainty estimation (GLUE), solution parameters (ParaSol), and Mark Chain Monte Carlo (MCMC). However, SUFI-2 is widely preferred among these approaches, since it can
provide the widest marginal parameter uncertainty intervals [22].

Hence, the SUFI-2 algorithm of the SWAT-CUP for an automatic calibration procedure was used in this study. In SUFI-2, the uncertainty of parameters is described as an interval that corresponds to the uncertainty of all variables. The algorithm takes into account the uncertainties of the parameters, the theoretical substructure of the model, and the measured data. The spread of uncertainty indicates a confidence interval. An interval (95PPU), which consists of the most suitable solutions for SUFI-2 algorithm at a 95% significance level, is achieved as a result.

Adequacy of the SWAT calibration was evaluated by adopting two statistical criteria, i.e. coefficient of determination ($R^2$), Nash-Sutcliffe efficiency (NSE). The $R^2$ is the proportion of variation explained by fitting a regression line and is viewed as a measure of the strength of a linear relationship between observed and simulated data [23,24]. The monthly reservoir outflow was collected from Office of Chief Engineer, Ongole from 01/01/2008 to 31/12/2016 and used for calibration and validation of the SWAT model.

2.4.9 Validation of SWAT model

Model Validation (evaluation) is used to quantify the uncertainties and confidences of simulations with measured data. The SWAT simulated results were validated using 2013-2016 observed mean monthly reservoir outflow.

3. RESULTS AND DISCUSSION

3.1 SWAT Model Performance

A SWAT model has been setup with the dataset of Gundlakamma subbasin and simulated total water yield from the subbasin during 2008 to 2016. The model was calibrated using reservoir outflow data. About four (2010 to 2013) years of discharges from reservoir was utilized in the calibration with the first two years (2008-2009) for model warm up.

3.2 Sensitivity Analysis of the SWAT

To overcome the simulation errors from the application of SWAT model, SWAT-CUP was used. It helped to calibrate the model and validate the results generated during simulation. For ease of calibration, sensitivity analysis of the input parameters was conducted (Fig. 5). The effect of input parameters describing watershed characteristics and land management practices on SWAT results were analyzed.

Fifteen hydrological parameters, i.e., soil depth (SOL_Z), biomixing efficiency (BIOMIX), plant uptake compensation factor (EPCO), groundwater revap coefficient (GW_REVAP), soil bulk density (SOL_BD), threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN), base flow alpha factor (ALPHA_BF), deep aquifer percolation fraction (RCHRG_DP), surface runoff lag time (SURLAG), hydraulic conductivity (SOL_K), soil available water capacity (SOL_AWC), channel effective hydraulic conductivity (CH_K2), soil evaporation compensation factor (ESCO), groundwater delay (GW_DELAY), and curve number (CN2) which are based on expert knowledge, were considered for the sensitivity analysis for discharge in the Gundlakamma subbasin. Global sensitivity analysis method in SWAT-CUP (Abbaspour 2012) was performed for these parameters. It is found that for Gundlakamma subbasin, the Delay time for aquifer recharge (GW_DELAY) is the most sensitive parameter followed Saturated hydraulic conductivity (SOL_K), Plant uptake compensation factor (EPCO), Available water capacity (SOL_AWC), Moisture condition II curve number (CN2), Threshold water level in shallow aquifer for base flow (REVAP), Base flow recession constant (ALPHA_BF), Maximum rooting depth in soil (RDMX), Surface runoff lag coefficient (SURLAG) and Soil evaporation compensation coefficient (ESCO). These ten (Table 2) of the most sensitive parameters with the identified desired parameter range were selected further for model calibration.

The rank of the sensitivity parameters was measured using the absolute t-stat value and p-values to determine the significance of the sensitivity. The parameters were more sensitive if the absolute t-stat value is more and p-value is close to zero. The sensitivity analysis of the input parameters is presented in Table 2.

The model has strong predictive capability with $R^2$ as 0.87 in calibration and 0.72 in validation and NSE as 0.79 in calibration period and 0.65 in validation period (Table 3). This result confirmed that the SWAT model performed well in this subbasin as statistical model efficiency criteria fulfill the requirement of $R^2 > 0.6$ and NSE >0.5 [24].
3.3 Simulation of Available Water Resources

The model provided detailed output on different components of water balance like rainfall, surface runoff, ground water contribution to flow, lateral flow, water yield, soil water content and actual evapotranspiration of the sub basin.

3.4 Change of Land use and Land Cover from 2010-11 to 2014-15

To study the impact of LULC change on water yield of subbasin, the model was run keeping all other conditions same except change in area of land use in the subbasin. The LULC map has been prepared for the year 2014-15 in anticipation of change in land use area and details were presented in Table 4.

There was not much change in the area of different land uses except paddy area. The change in land use controls the water yield of surface streams and ground water aquifer and thus amount of water available in the sub basin. The area under paddy had been reduced from 19.44% to 19.20% and Kharif area was slightly increased from 13.43% to 13.47% and remaining all the land uses were same. The stream flow, base flow, percolation and evapotranspiration was slightly increased but only surface runoff was reduced.

3.5 Average Monthly Basin Values

The simulated average monthly basin values are presented in the Table 5. The hydrological parameters such as percolation, surface flow, ground water contribution to flow indicated relationship with precipitation. Actual evapotranspiration (ET) 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 month of September also. This is mainly due to the kharif crops namely, paddy, chillies, cotton and redgram grown in the subbasin.

Whenever there is rainfall, surface runoff and lateral flow contributed to the stream flow. The maximum amount of surface runoff contribution to flow simulated was 49.03 mm in the month of October that coincided with the highest amount of rainfall recorded during the month. Actual ET values varied from 12.16 mm to 62.48 mm.

3.6 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 864.20 mm. This precipitation was apportioned in to water balance components in which evapotranspiration has accounted high followed by surface runoff. Lateral flow contributed less to the flow. The average annual ET of the basin is around 50% of the precipitation. Thanapakpawin et al. [25] also reported that simulated average annual evapotranspiration was major process and accounting for 74% of basin-wide estimated precipitation.

3.7 Average Annual Basin Values with 2014-15 LULC

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 6. The average annual precipitation was 843.5 mm. This precipitation was apportioned into water balance components in which ET was accounted high followed by deep aquifer recharge.

Surface runoff and lateral flow contributed less to the flow. The average annual ET of the basin is around 50% of the precipitation.

3.8 Average Monthly Basin Values of Water Balance Components during 2010-11 and 2014-15

The monthly basin values are presented in the Table 7. The hydrological parameters such as percolation, surface flow, ground water contribution to flow indicated good relationship with precipitation. Generally, ET will be more during April to August in a year. However, ET was more even during the month of September and same was observed during the year 2010-11. This is mainly due to the Kharif crops namely, paddy, chillies, cotton and redgram grown in the catchment.

Surface runoff was more in October (50.63 mm) which coincided with the highest amount of rainfall (170.58 mm) received during the month. Similarly, the water yield was highest in the
month of October which is related to surface runoff and lateral flow. The surface runoff was 49.03 mm with highest rainfall of 175.63 mm for the year 2010-11 with different LULC. Soil moisture values varied from 80.80 mm to 280.41 mm under 2010-11 LULC where as it was 80.75 mm to 280.60 mm under 2014-15 LULC.

The summary of the ratio of allocation of precipitation into different components of water balance under different LULC were presented in the Table 9.

The above result clearly indicated the impact of change in land use on components of water balance. The surface runoff contribution to flow has been decreased during 2014-15 due to reduction in paddy area. The Evapotranspiration was increased due to increase in area during kharif and rabi.

Table 1. Percentage area under different slope classes of study area

| Land slopes (%) | Area (ha) | Area (%) |
|-----------------|-----------|----------|
| 0-4             | 38106.15  | 28.63    |
| 4-6             | 30606.17  | 23.00    |
| 6-8             | 22952.15  | 17.25    |
| >8              | 41414.63  | 31.12    |

Fig. 5. Scattered diagram of observed and simulated mean monthly discharges during 2010-2012

Fig. 6. Scattered diagram of observed and simulated mean monthly discharges during 2013-2016
Table 2. Sensitivity analysis of the input parameters of SWAT

| S. No | Parameter Name | Definition | Units | t-Stat | P-Value | Rank |
|-------|----------------|------------|-------|--------|---------|------|
| 1     | GW_DELAY       | Delay time for aquifer recharge | days   | 33.76  | 0.00*   | 1    |
| 2     | SOL_K          | Saturated hydraulic conductivity | mm/hr  | 3.54   | 0.00*   | 2    |
| 3     | EPCO           | Plant uptake compensation factor | -      | 2.40   | 0.02**  | 3    |
| 4     | SOL_AWC        | Available water capacity | -      | 2.02   | 0.04**  | 4    |
| 5     | CN2            | Moisture condition II curve number | -      | 1.33   | 0.18    | 5    |
| 6     | REVAP          | Threshold water level in shallow aquifer for base flow | mm     | 1.27   | 0.20    | 6    |
| 7     | ALPHA_BF       | Base flow recession constant | -      | 1.27   | 0.21    | 7    |
| 8     | RDMX           | Maximum rooting depth in soil | mm     | 0.65   | 0.52    | 8    |
| 9     | SURLAG         | Surface runoff lag coefficient | -      | 0.21   | 0.83    | 9    |
| 10    | ESCO           | Soil evaporation compensation coefficient | -      | 0.06   | 0.95    | 10   |

* 1% level of significance; ** 5% level of significance

Table 3. Statistical performance indicators during calibration and validation period

| Variable                  | NSE | R²  |
|---------------------------|-----|-----|
| Calibration (2010-2012)   | 0.79| 0.87|
| Validation (2013-2016)    | 0.65| 0.72|

Table 4. Details of land use and land cover for different years in Gundlakamma subbasin

| S. No. | Land use      | 2010-11 Area (ha) | Area (%) | 2014-15 Area (ha) | Area (%) |
|--------|---------------|-------------------|----------|-------------------|----------|
| 1      | Kharif only   | 17870.13          | 13.43    | 17870.52          | 13.47    |
| 2      | Scrubland     | 12693.60          | 9.54     | 12693.60          | 9.54     |
| 3      | Rabi only     | 30605.16          | **23.00**| 30924.52          | **23.24**|
| 4      | Current fallow| 32986.46          | 24.79    | 32986.46          | 24.79    |
| 5      | Water Bodies  | 4844.04           | 3.64     | 4844.04           | 3.64     |
| 6      | Paddy         | 25877.04          | **19.44**| 25565.57          | **19.16**|
| 7      | Barren land   | 4411.37           | 3.31     | 4411.37           | 3.31     |
| 8      | Urban         | 744.38            | 0.56     | 744.38            | 0.56     |
| 9      | Forest        | 456.68            | 0.34     | 456.68            | 0.34     |
| 10     | Plantation    | 2590.25           | 1.95     | 2590.25           | 1.95     |

Table 5. Average annual basin values of different components of water balance during 2010-11

| Process                  | Average Annual Value (mm) | Contribution (%) |
|--------------------------|---------------------------|------------------|
| Precipitation            | 864.20                    | -                |
| Surface runoff           | 211.08                    | 24.4             |
| Lateral flow through Soil| 7.00                      | 0.8              |
| Groundwater (shallow aquifer) | 47.59                | 5.5              |
| Deep aquifer recharge    | 178.68                    | 20.7             |
| Actual Evapotranspiration| 408.40                    | 47.2             |
Table 6. Average Annual Basin Values of different components of Water balance

| Process                                | Average Annual Value (mm) | Contribution (%) |
|----------------------------------------|---------------------------|------------------|
| Precipitation                          | 843.50                    |                  |
| Surface runoff                         | 210.67                    | 24.97            |
| Lateral flow through Soil              | 8.75                      | 1.03             |
| Groundwater contribution to flow       | 49.61                     | 5.88             |
| Deep aquifer recharge                  | 217.40                    | 25.77            |
| Actual Evapotranspiration              | 404.20                    | 47.91            |

Table 7. Average monthly basin values of different components of Water Balance in 2010-11

| Month | Rainfall (mm) | Surface Runoff (mm) | Water Yield (mm) | Actual ET (mm) |
|-------|---------------|---------------------|------------------|----------------|
| JAN   | 8.45          | 0.95                | 22.66            | 23.76          |
| FEB   | 16.98         | 4.57                | 24.13            | 23.29          |
| MAR   | 0.00          | 0.00                | 20.11            | 12.16          |
| APRL  | 13.43         | 0.66                | 19.02            | 13.82          |
| MAY   | 63.06         | 18.09               | 35.73            | 24.27          |
| JUN   | 64.77         | 7.47                | 24.12            | 39.64          |
| JULY  | 112.52        | 18.01               | 34.81            | 50.52          |
| AUG   | 131.10        | 27.69               | 44.99            | 62.48          |
| SEP   | 127.79        | 24.28               | 43.56            | 61.63          |
| OCT   | 175.63        | 49.03               | 70.00            | 47.96          |
| NOV   | 87.33         | 27.46               | 49.74            | 27.66          |
| DEC   | 63.57         | 32.98               | 56.05            | 21.73          |
| Total | 864.63        | 211.19              | 444.92           | 408.92         |

Table 8. Average Monthly Basin values of different components of water balance during the year 2014-15

| Month | Rainfall (mm) | Surface Runoff (mm) | Water Yield (mm) | Actual ET (mm) |
|-------|---------------|---------------------|------------------|----------------|
| JAN   | 8.29          | 1.09                | 25.41            | 26.00          |
| FEB   | 15.34         | 3.84                | 26.70            | 17.69          |
| MAR   | 0.00          | 0.00                | 24.45            | 11.86          |
| APRL  | 13.41         | 0.96                | 24.69            | 12.41          |
| MAY   | 67.08         | 23.84               | 47.60            | 24.49          |
| JUN   | 54.13         | 6.10                | 28.45            | 37.42          |
| JULY  | 99.64         | 14.44               | 36.79            | 49.51          |
| AUG   | 130.51        | 26.20               | 48.13            | 64.18          |
| SEP   | 123.58        | 22.53               | 44.52            | 65.29          |
| OCT   | 170.58        | 50.63               | 73.48            | 45.82          |
| NOV   | 95.13         | 31.64               | 54.71            | 26.97          |
| DEC   | 66.22         | 29.51               | 53.78            | 23.00          |
| Total | 843.91        | 210.78              | 488.71           | 404.64         |

Table 9. Water balance components under different LULC

| Ratio                        | 2010-11 | 2014-15 |
|------------------------------|---------|---------|
| Stream flow /precipitation   | 0.31    | 0.32    |
| Base flow                    | 0.21    | 0.22    |
| Surface runoff               | 0.79    | 0.78    |
| Percolation /precipitation   | 0.51    | 0.52    |
| ET/precipitation             | 0.47    | 0.48    |
4. CONCLUSIONS

The assessment of water resources demand for various purposes is of utmost importance without which it is difficult to prepare any developmental plan. The information on availability of water resources and water demand and supply, reliability, water management technologies can definitely aid in efficient usage of water. The Soil and Water Assessment Tool (SWAT) is an effective tool for simulating the water resources in the basin. The information is required to the water users / managers in the catchment or command area for planning of cropping pattern and cropped area in a subbasin to manage the scarcity of water resources among the different sectors of water use.

A study has been conducted on the Gundlakamma subbasin to simulate the water availability and water consumption in the subbasin. The data base has been collected using the secondary data and field survey. SWAT model was applied to simulate the available water resource and reservoir volume in subbasin. The SWAT model was calibrated and validated with the observed discharges from the reservoir.

Base on the research work the following conclusions were drawn:

1. The Soil and Water Assessment Tool (SWAT) can be effectively applied to simulate the flow into a reservoir in the Gundlakamma subbasin.
2. The most sensitive input parameters for simulating water yield were delay time for aquifer recharge (days) and saturated hydraulic conductivity (mm/hr) for the Gundlakamma subbasin.
3. The average annual surface runoff and actual evapotranspiration were 211.08 mm and 408.40 mm in the Gundlakamma subbasin.
4. Increase in urbanization increases more surface runoff and reduces infiltration in the Gundlakamma subbasin. Increase in plantation area lead to more evapotranspiration.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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