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# Assessment of surface runoff and soil loss in the Manair river Sub-Basin

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**Abstract**
The main objective of this study is to identify suitable technological interventions for sustainable management based on runoff and soil loss under the current scenario using the Soil and Water Assessment Tool (SWAT) model.A SWAT model has been setup with the dataset of the upper Manair sub-basin and simulated total Runoff and soil loss from the sub-basin from 1951 to 2020. The model was calibrated from (2011-2015) and validated from (2016-2020). The two statistical model performance measures namely Nash Sutcliffe Efficiency (NSE) and coefficient of determination ($R^2$) used in calibration and validation. The model has a predictive capability with $R^2$ as 0.87 in calibration and 0.807 in validation and NSE as 0.79 in the calibration period and 0.65 in the validation period. The surface runoff 216.53 mm and Soil loss 9.45 t $ha^{-1}$. Site selection for soil and water conservation measures is carried out by overlaying slope, soil, land use/land cover, and stream order maps. The sites for check dams and percolation tanks were identified in the agriculture and wasteland zone. The proposed structures will aid in improving the availability of groundwater resources.

**Keywords:** Manair river sub-basin; Soil loss; Surface Runoff; SWAT applicationand Technological interventions

## Introduction
Water is one of the most valuable natural resources which support human health, economic development and ecological diversity. The world's total water resources were estimated as $1.36 \times 10^8$ ha- m, of these 97.5% occurs as salt water in the oceans, 2.5% occur as fresh water, out of which only 0.3% can be directly utilized by living organisms. In India, the per capita water availability has decreased from 5177 $m^3$ in 1951 to 1654 $m^3$ in 2007, thereby approaching water scarce condition of per capita availability of less than 1000 $m^3$ per year by 2050's (MOWR, 2008) [7]. Therefore, proper management of water resources and its quality becomes very important. Water scarcity is one of the most crucial problem faced all over the world in general and India in particular.

Assessment of runoff and soil loss from the river basin/watershed is the basic step in planning and design of erosion control measures, sizing of conveyance structures, and sediment retention measures. For designing such structures, data on runoff, peak rate of runoff, and other related parameters are pre-requisite. The accuracy of these parameters greatly influences the design process. SWAT is one such conceptual model, semi-distributed and continuous in time, and was developed to predict the effects of different uses, land covers, and soil management on water and sediment production as well as water quality (Duraes *et al.*, 2011) [3] and predominantly used for agricultural watersheds. For implementation and greater flexibility in simulation, the model has been highlighted in relation to others. Recently due to climate change, it is projected that spatial and temporal patterns of rainfall in different parts of the country will be changed and there will be an increase in the intensity of rainfall with greater monsoon variability. This unprecedented change is expected to have a severe impact on the spatial and temporal distribution of runoff and finally on soil loss estimation for future planning and management.

At the Upper Manair dam, the physiographic of the area is undulating having a slope of 1-6%, slightly eroded, and moderately drained. It consists of mainly two types of soils; clay loam soils occupy an area of 92% and the remaining 8% soils are clay soils in the catchment which leads to more runoff and soil loss at the Upper Manair dam. To understand the issues which are affecting the runoff and soil loss in the sub-basin, the application of simulation models has become indispensable for the understanding of their hydrological processes. Keeping the increased soil loss due to high runoff in the Manair river sub-basin, the present study is proposed.

## Material and Methods
### Study area
The present study is proposed in Manair river sub-basin, Narmala Village, Gambhiraopet Mandal, Sirisilla District Telangana State which lies between 18°26′ 27.22″N latitude and 78°17′33.93″E longitude, 18°12′52.43″N latitude and 78°40′15.88″E longitude, 18°02′02.08″N latitude and 78°27′59.22″E longitude, 17°42′33.12″N latitude and 78°43′48.41″E longitude with an altitude of 456m above mean sea level. The total geographical area of the sub-basin is 2,165 km$^2$ and flows through the Telangana state. The climate of the basin are extreme with hot summers and cold winters. It experiences southwest monsoon rains from June to September with an average annual rainfall of 907 mm. May is the hottest month with a maximum temperature of 44 ºC and a minimum temperature of 27 ºC in the month of December. The river Manair, which is the tributary of Godavari River Basin flowing through Karimnagar urban and suburban area, is the major source of water supply in the area. The location map of the study area was shown in Fig 1.

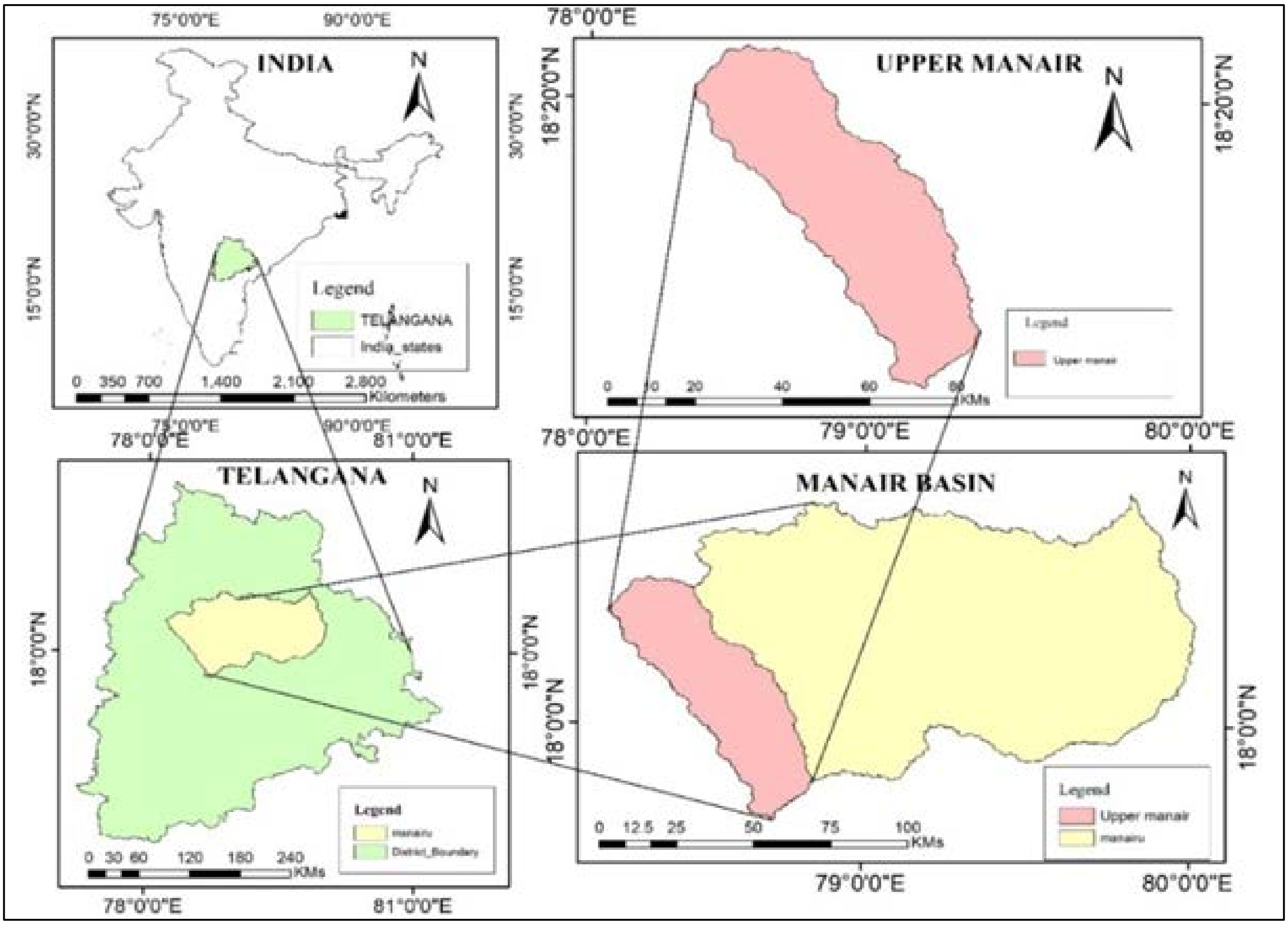



**Fig 1:** Location map of Upper Manair sub-basin

### Methodology
The methodology involved in the estimation of runoff and soil loss using SWAT is described in the flow chart given below (Fig 2). It involves delineation of the watershed, HRU definition, providing weather data inputs, and output generation.

### Soil and Water Assessment Tool (SWAT)
SWAT is an evaluating tool for soil and water developed by the USDA-Agricultural Research Service (Arnold *et al.*, 1998) [2]. This model was developed for the investigation of watersheds with areas going from a few hundred km² to several thousand km². In this model, the watershed was divided into a number of sub-watersheds which were characterized by dominant land use, soil, and slope classes. The basic spatial unit of the calculation is the Hydrological Response Unit (HRU) which is the result of the combination of a soil type, a class of land cover, and a slope class.

In the SWAT model, surface runoff was estimated by a modified Soil Conservation Service (SCS) curve number equation using daily precipitation data based on soil hydrologic group, land use/land cover characteristics, and antecedent soil moisture. Despite the empirical nature, this approach has been proved to be successful for many applications and a wide variety of hydrologic conditions (Gassman *et al.*, 2007) [4]. The runoff from each sub-basin was routed through the stream network to the main basin outlet (Neitsch *et al.*, 2005) [10] to obtain the total runoff for the watershed.

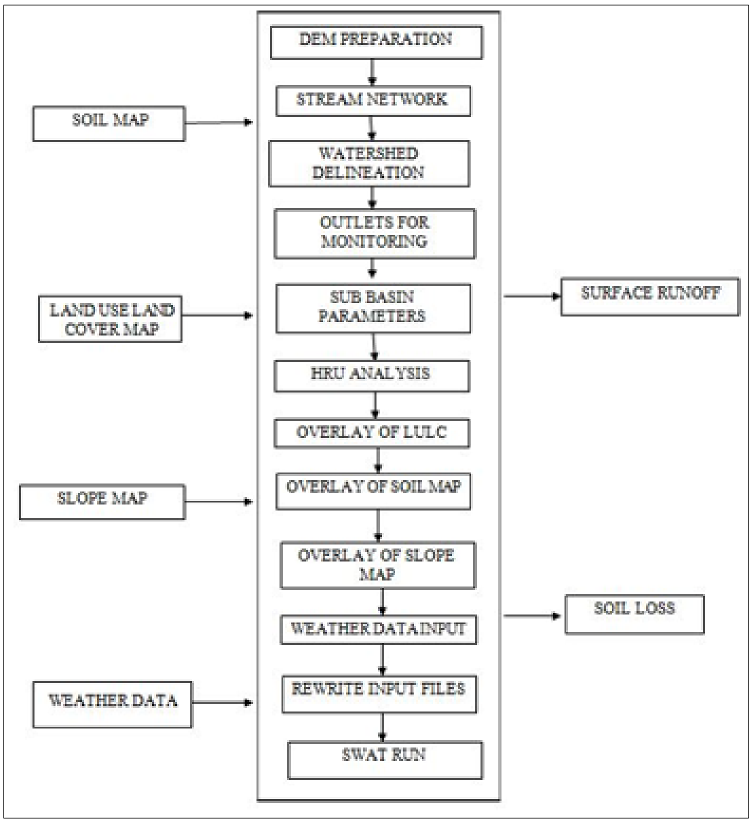



**Fig 2:** Flow chart of steps involved in SWAT simulation

## Preparation of thematic maps of study area

The basic maps required for the Arc SWAT include digital elevation model, soil, land use land cover 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 44N was used as the co-ordinate 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.

## Delineation of Watershed

The Digital Elevation Model was downloaded from USGS (United States of Geological Survey) web site given with a resolution of 30 m x 30 m. Two tiles were downloaded and mosaicing and rectification was done. The projection UTM, the spheroid type (WGS 1984) and Datum of WGS 84 and 44N zone has been applied to DEM.

## Land Use/Land Cover Map

The LULC map was prepared for the study area using IRS P6, and LISS III images of December 2011 and September 2012. The information from the LISS III image and top sheets was utilized for the classification of land cover generation of training sets. Ground truth survey was carried out by walking around the field boundaries two times (*rabi* 2011 and *Kharif* 2012) from 2011 to 2012 using GPS.

## Soil Texture Map

The soil map (1: 250,000) developed by NBSS & LUP has been taken as a reference map and clipped to the catchment area. The soil textural classes were identified. In addition to that, the soil map prepared by the SWAT group for India was also considered to ascertain the types of soil. The different types of the soils in the study area were clay, clay loam, and rocks with 69%, 6.37%, and 25.03% area representation respectively.

## Simulation with the SWAT model

The base model has been developed for the period from 1951 to 2020 and simulated the Runoff and soil loss and calibrated to produce accurate simulation results namely, calibration, verification, and validation. Calibration and validation are important processes for any simulation model to understand its certainties, confidence levels, and limitations.

## Sensitivity Analysis

The selection of calibration parameters was based on their significance to the simulated output. The parameter significance was determined by trial & error, by literature research (Narsimlu *et al.*, 2015) [8]. The sensitivity analysis of calibration parameters was carried out with the sensitivity analysis which uses the statistical parameters *t-stat* and *p-value* for determining the parameter sensitivity. The *t-stat* is the coefficient of a parameter divided by its standard error and a low *p-value* (< 0.05) indicates that the null hypothesis can be rejected. Summed up, the larger the absolute value of the *t-stat* and the smaller the *p-value* is, the more sensitive the parameter (Abbaspour, 2007) [1]. To assess the goodness-of-fit of the model, coefficient of determination ($R^2$) and the Nash-Sutcliffe efficiency coefficient (NSE) were used.

## Coefficient of determination ($R^2$)

The coefficient of determination $R^2$ is defined as the squared value of the coefficient of correlation and is given by equation.

$$R^2 = \frac{\sum_i[(Q_{m,i} - \bar{Q}_m)(Q_{s,i} - \bar{Q}_s)]^2}{\sum_i(Q_{m,i} - \bar{Q}_m)^2 \sum_i(Q_{s,i} - \bar{Q}_s)^2}$$

Where, $Q_m$ is the observed stream flow on day $i$ ($m^3/s$), $Q_s$ is the simulated stream flow on day $i$ ($m^3/s$), and bars indicate averages. The value of $R^2$ranges from 0 to 1. A value close to 1.0 indicates good performance (good correlation) of the model and the value close to 0.0 indicates poor performance (poor correlation) of the model.

**Nash-Sutcliffe efficiency coefficient (NS)**

The Nash-Sutcliffe efficiency coefficient (Nash and Sutcliffe, 1970) [9] is used to assess the predictive power of the hydrological models.

$$NS = 1 - \frac{\sum_i (Q_m - Q_s)_i^{\,2}}{\sum_i (Q_{m,i} - \bar{Q}_s)^2}$$

Where,
NS is the Nash-Sutcliffe efficiency coefficient.

The value of NS varies from 1.0 (perfect fit) to minus infinity. An efficiency of lower than zero indicates that the mean values of the observed time series would have been a better predictor than the model (Krause *et al*., 2005). The NS value of 0 indicates that the model predictions are as accurate as the mean of the observed data.

**Future climate change scenarios**

A Regional Climate Model (RCM) is the best tool for dynamic downscaling of climate data from the output of a Global Climate Model (GCM) and enables making predictions for a particular region. The data pertaining to Representative Concentration Pathways (RCPs) 4.5 and 8.5 scenarios have been taken to obtain the information on geo and restricted environmental conditions. In order to assess the future water requirement for the crops grown in Upper manair sub basin, the future climatic data was collected from Climate Change, Agriculture and Food security website: http://gismap.ciat.cgiar.org/MarkSimGCM/.

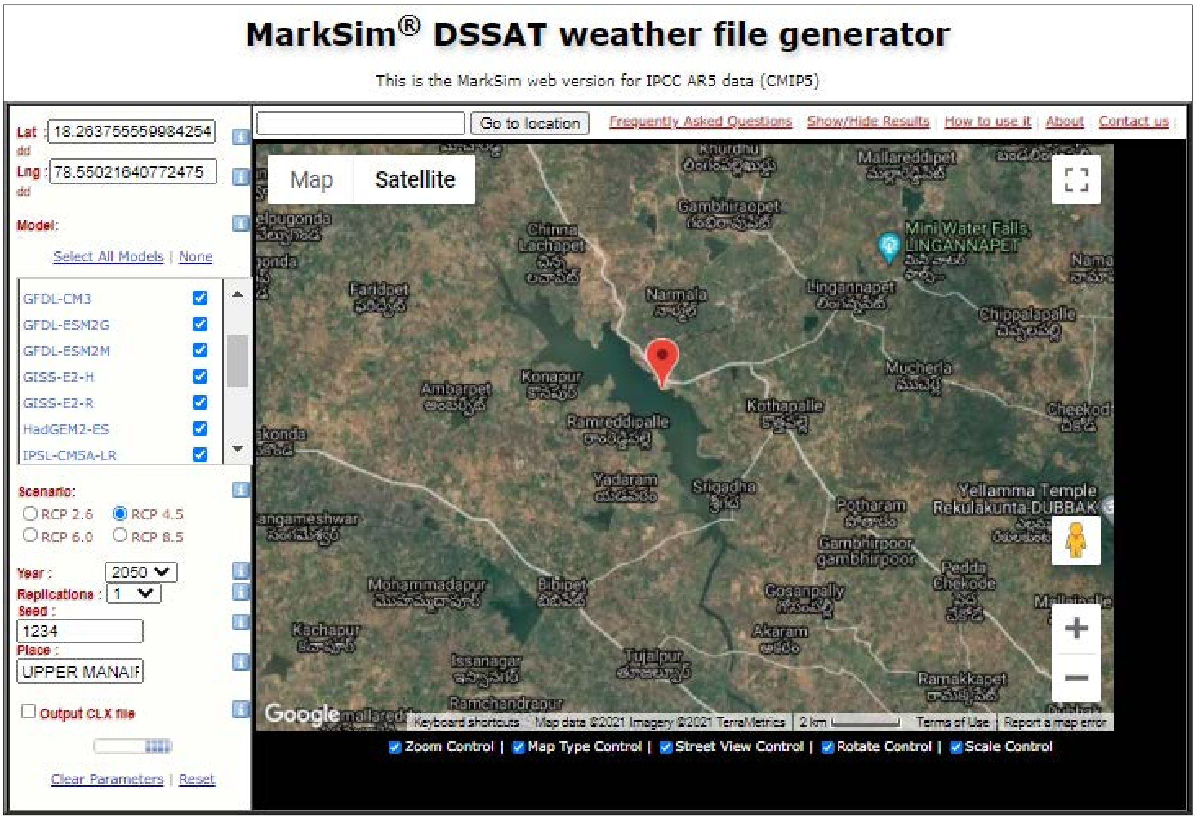



**Fig 3:** Downloading the future weather data from the Marksim DSSAT weather file generator

**Results and Discussion**

**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 validated the results generated during simulation. For ease of calibration, sensitivity analysis of the input parameters was conducted. The effects of input parameters describing watershed characteristics and land management practices on SWAT results were analysed. The sensitivity analysis of Upper Manair sub basin of the SWAT model has utilised ten input parameters. The rank of the sensitivity parameters was measured using the absolute t-stat value and p-values to determine significance of the sensitivity. The parameters were more sensitive when the absolute t-stat value is more and p-value is close to zero. Ground water delay and saturated hydraulic conductivity was found to be most sensitive parameters for Upper Manair sub basin. Parameters like available water content, plant uptake compensation factor and SCS runoff curve number have shown higher sensitivity as well. The sensitivity analyses of the input parameters were presented in Table1.

The below mentioned sensitive input parameters have been considered during the calibration, validation processes of the sub basin before applying the model for any scenario study. The parameters were calibrated using auto calibration procedure.

**Table 1:** Sensitivity analysis of the input parameters of SWAT

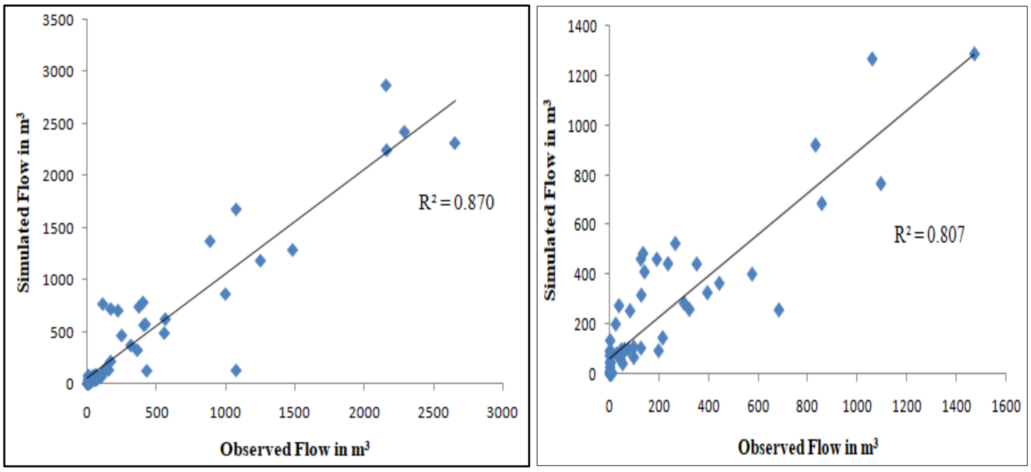
| S. No | Parameter Name | t-Stat | P-Value | Rank |
|---|---|---|---|---|
| 1 | Delay time for aquifer recharge (days) | 33.76 | 0.00* | 1 |
| 2 | Saturated hydraulic conductivity (mm/hr) | 3.54 | 0.00* | 2 |
| 3 | Plant uptake compensation factor | 2.40 | 0.02** | 3 |
| 4 | Available water capacity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

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

The graphical and statistical approaches were used to evaluate the SWAT model performance while the acceptance values were obtained from discharge of reservoir. Hydrologic calibration resulted good predictive efficiency at the monthly time step of the sub basin when compared to measured flow data.

**Simulation of Runoff and Soil loss in the Upper Manair Sub basin**

A SWAT model has been setup with the dataset of upper Manair sub basin and simulated total water yield from the sub basin during 1951 to 2020. The model was calibrated from (2011-2015) and validated from (2016-2020) of observed data. The model has strong predictive capability with $R^2$ as 0.87 in calibration and 0.807 in validation and NSE as 0.79 in calibration period and 0.65 in validation period. This result confirmed that the SWAT model performed well in this sub basin as statistical model efficiency criteria full fill the requirement of $R^2$> 0.6 and NSE >0.5 (Moriasi *et al.*, 2007).




(a) (b)

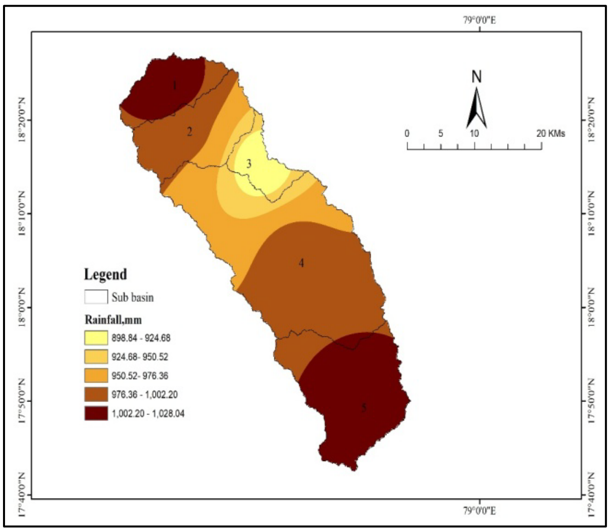
**Fig 4:** Scattered diagram of observed and simulate mean monthly discharges during (a) 2011-2015 and (b) 2016-2020.

**Spatial variation of hydrological components in Upper Manair sub basin under RCP 4.5.**

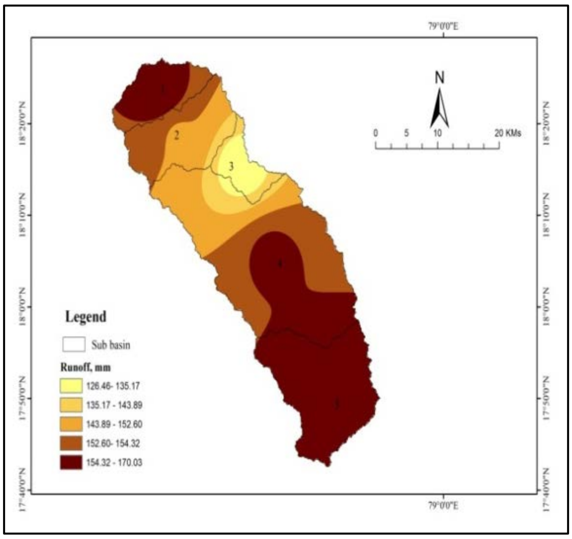
The spatial variation of normal rainfall in upper Manair sub basin was depicted in Fig 5 (a). The normal rainfall was more in sub basin 1 (1028.04 mm) and moderately in sub basin 2 and 4. There was less amount of normal rainfall in sub basin 3 (898.84 mm).

The spatial variation of surface runoff was shown in Fig 5 (b). Surface runoff was more in sub basin 1, 4 and 5. There was less amount of surface runoff in sub basin 3. The highest amount of 170.03 mm and lowest amount of 126.46 mm has more barren land / scrub land and rock out which lead to more surface runoff.

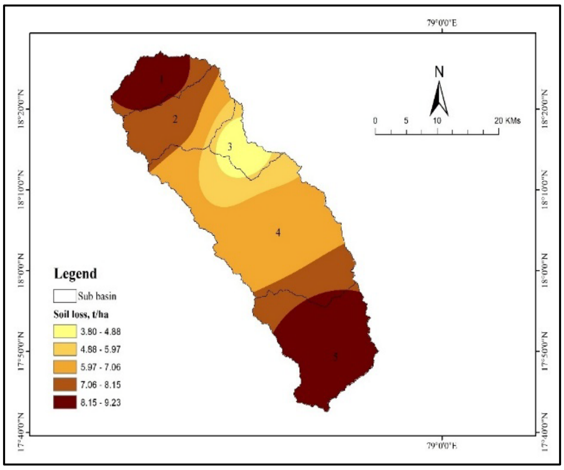
The spatial variation of soil loss in Upper Manair sub basin under RCP 4.5 was shown in Fig 5(c). Soil loss was more in sub basin 1 and 5, highest amount was 9.23 t $ha^{-1}$ $yr^{-1}$ and lowest amount of soil loss simulated as 3.80 t $ha^{-1}$ $yr^{-1}$ in sub basin 3.




(a)




(b)

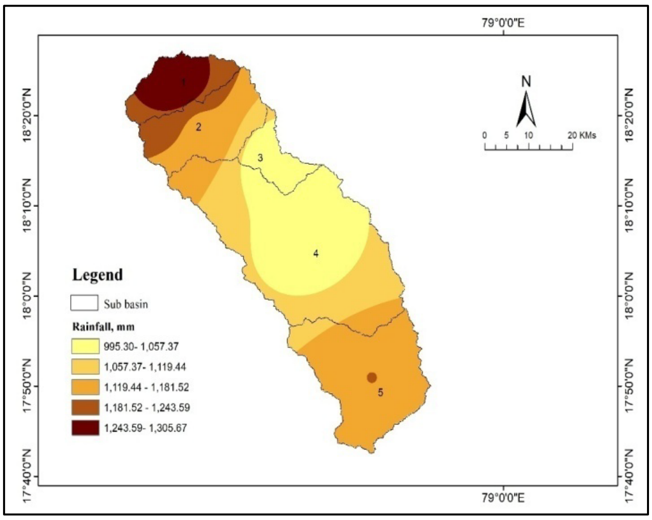



(c)

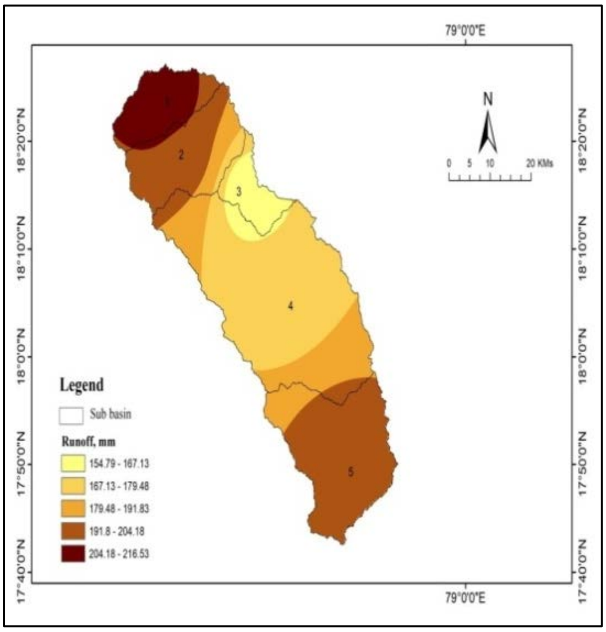
**Fig 5:** Spatial variation of (a) rainfall (b) runoff (c) soil loss in Upper Manair sub basin under RCP 4.5

**Spatial variation of hydrological components in Upper Manair sub basin under RCP 8.5.**

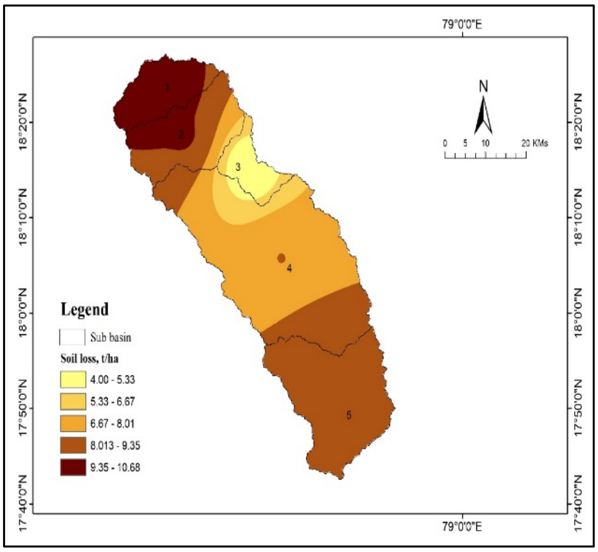
The spatial variation of normal rainfall in upper Manair sub basin was depicted in Fig 6 (a). The normal rainfall was more in sub basin 1 (1305.67 mm) and moderately in sub basin 2 and 5. There was less amount of normal rainfall in sub basin 3 (995.30 mm).




(a)




(b)




(c)

**Fig 6:** Spatial variation of (a) rainfall (b) runoff (c) soil loss in Upper Manair sub basin under RCP 8.5.

The spatial variation of surface runoff was shown in Fig 6 (b). Surface runoff was more in sub basin 1. There was less amount of surface runoff in sub basin 3. The highest amount of 216.53 mm and lowest amount of 154.79 mm has more barren land/scrub land and rock out which lead to more surface runoff.

The spatial variation of soil loss was shown in Fig 6(c). Soil loss was more in sub basin 1 and 2; highest amount was 10.68 t $ha^{-1}$ $yr^{-1}$ and lowest amount of Soil loss simulated as 4.0 t $ha^{-1}$ $yr^{-1}$ in sub basin 3.

**Simulation of runoff and soil loss**

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, actual evapotranspiration and soil loss of the sub basin.

In order to present the order of magnitude of these allocations of precipitation in to different components of water balance, the average annual precipitation was 949.2 mm, surface runoff was 170.55 mm and soil loss of the basin is around 7.95 t $ha^{-1}$.

**Water balance components under climate change scenarios**

Two different scenarios RCP 4.5 and RCP 8.5 were proposed to evaluate the effect of climate change on runoff and soil loss estimation in Upper Manair sub basin. The surface runoff under RCP 4.5 was increased from 154.79 mm to 216.53 mm and under RCP 8.5 it was increased from 126.46 mm to 170.03 mm and Soil loss under RCP 4.5 was increased from 7.95 t $ha^{-1}$to 9.04 t $ha^{-1}$and under RCP 8.5 was 7.95 t $ha^{-1}$to 9.45t $ha^{-1}$.

Suitable structures in the sub basin will definitely augment the ground water resources. Soil and water conservation measures were planned for catchment area treatment based on estimated morphological features of basin. Site selection for soil and water conservation measures is carried out by overlaying the slope, soil, land use/land cover and stream order maps. The multilayer integration of land use/ land cover, soil, slope, flow direction, drainage and settlement gave the suitability units for identifying sites for percolation tanks and check dams (Pandey *et al.*, 2011, Prasad *et al.*, 2014) [11, 12]. Factor layers (maps) were incorporated in ArcMap multi criteria evaluation analysis, using the weighted overlay function in the ArcGIS analyst. Finally, a suitability map was developed that show the potential sites for different conservation structures in study area.

**Identification of potential sites for water harvesting structures**

The sites for check dams were identified in agriculture, forest and waste land zone. The sites for percolation tanks were identified in waste lands. The proposed structures will definitely aid in improving the availability of ground water resources.

Based on the information about morphological parameters, suitable sites were identified for consideration of conservation structures following the criteria has been decided for identifying the suitable sites for conservation measures, namely check dams and percolation tanks. The site for Check dam can be selected on 2nd or 3rd order streams in moderate to well drained conditions with slope < 10% and land use may be Agricultural areas/Waste land/Forest areas. Criteria for selection of site for Percolation tank is 2nd or 3rd order streams on well drained to excessively drained conditions with slope <3 % and landuse may be waste land. Check dams are recommended for drainage line treatment. This structure helps in reducing velocity of runoff water, water harvesting and also ground water recharge. Percolation tanks are suggested across streams and bigger gullies to impound part of runoff water and thereby recharging of ground water.

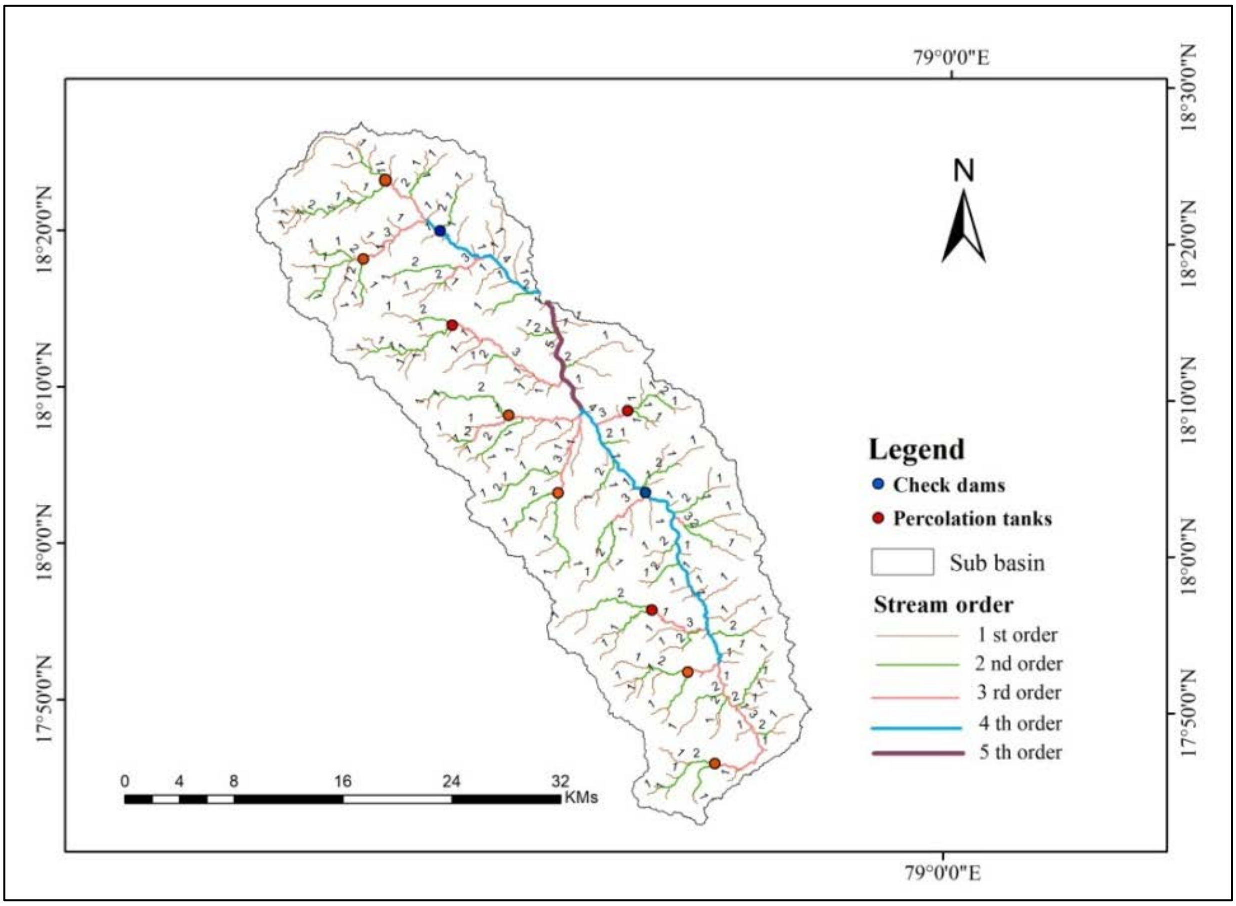



**Fig 7:** Suitable site for Percolation tanks and Check dams in Upper Manair sub basin

**Conclusion**

From the above results, it is concluded that the water resources are very vital renewable resources that are the basis for the survival and development of any society. During the last few decades there has been sharp increase in water consumption owing to the population explosion, rapid industrial development and recent trends in climate change. Available water is not sufficient to meet the demand for the prevailing sectors of water use in Upper Manair sub basin. There is a need to augment the water resources for future by adopting water management technologies and planning soil and water conservation measures for achieving sustainability of water resources in the Upper Manair sub basin. Improved water use efficiency of surface water in addition to increased availability of ground water will lead to hydrological sustainability in the sub basin.

Based on the results, the following conclusions were drawn:

1. The Soil and Water Assessment Tool (SWAT) can be effectively applied to simulate the runoff and soil loss in the Upper Manair sub basin.
2. The average annual precipitation, surface runoff and soil loss are 949.2 mm, 170.55mm and 7.95 t $ha^{-1}$ respectively during 1951- 2020.
3. The model has strong predictive capability with $R^2$ as 0.87 in calibration and 0.807 in validation and NSE as 0.79 in calibration period and 0.65 in validation period
4. The percentage increase in projected rainfall with RCP 4.5 scenario for 2020, 2030, 2040 and 2050 with 2010 will be 2.75%, 5.36%, 7.55% and 10.97% respectively.
5. The percentage increase in projected rainfall with RCP 8.5 scenario for 2020, 2030, 2040 and 2050 with 2010 will be 5.70%, 10.79%, 15.35% and 19.48%.
6. The sites for check dams were identified in agriculture and waste land zone. The sites for percolation tanks were identified in waste lands.

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