

# Chapter 66

## Impact of Water Conservation Structures on Hydrology of a Watershed for Rural Development



Vinit Lambey, A. D. Prasad, Arpit Chouksey and Indrajeet Sahu

**Abstract** A watershed is an area of land from which all rain water drains to a common location. In their natural state, streams and their associated floodplains provide a variety of important functions including the movement of water and sediment, storage of flood waters, recharge of groundwater, treatment of pollutants, dynamic stability, and habitat diversity. Disturbances to this system, either natural or human-induced, places stress on the system and has the potential to alter structure and/or impair the ability of the stream to perform ecological functions. Water conservation structures are helpful in maintaining the desired flow requirement and sediment yield within the watershed area. In this study, Jonk River, a tributary of Mahanadi basin has been selected to assess the impact of conservation structures for disaster risk reduction, sustainable agriculture and rural development. The outlet of Jonk River is located near Rampur in Chhattisgarh. Total area of the watershed is computed as 3424 km<sup>2</sup>. Soil and Water Assessment Tool (SWAT) has been used to calculate the discharge and sediment flow on daily and monthly basis for the year of 2001 considering two case scenarios i.e. with and without ponds as conservation structure (20 ponds in the villages are considered along the buffer area of the centreline of jonk river). The simulated discharge and sediment flow data has been compared with the observed data and the correlation coefficient is found to be 0.84 & 0.77 respectively. The annual discharge and sediment flow value in “with pond scenario” has been detected to be reduced by 69.27 and 64.10% respectively.

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The results observed in the present work can be used for site suitability analysis of soil and water conservation structures in the areas those are prone to soil erosion and floods. The study also reveals that the applications of Geographic Information Systems (GIS) and Geospatial Data Management can be used efficiently for watershed management and rural development.

**Keywords** Watershed · SWAT · Sediment flow · Discharge · Geoinformatics

## 1 Introduction

Water is an essential element for survival of living things. It is vital for increasing growth of agriculture, industries and leads to rural development, economic development of the region. A watershed is comprised of land areas and channels and may have lakes, ponds or other water bodies. The flow of water on land areas occurs not only over the surface but also below it in the unsaturated zone and further below in the saturated zone [8] which can be enhanced by providing water conservation structures. This results in improvement of ground water level and can significantly contribute in development and management of rural areas. To deal with water management issues especially in rural areas, one must quantify the different elements of hydrologic processes taking place within the area of interests and analyse them. Geographic Information Systems (GIS) is a suitable tool for the efficient management of large and complex database and to provide a digital representation of watershed characteristics used in hydrological modelling. It has improved the efficiency of modelling process and ultimately increased the estimation capabilities of hydrological modelling [1].

Hydrological models coupled with geoinformatics such as MIKE-SHE, TOPMODEL, HEC-GeoHMS, VIC, WATFLOOD and SWAT, are capable of simulating spatio-temporal variations in hydrological processes. Many previous studies have demonstrated the ability of SWAT in detecting the impacts of land use and climate change on hydrological components in different areas [2, 4, 5, 7, 9]. SWAT model is physically based, efficient and capable of continuous simulation for a long period. Therefore, Soil and Water Assessment Tool (SWAT) model has been chosen to simulate or estimate the changes in runoff and sediment yield over daily, monthly and annual timescales.

In the present study SWAT Model is used to assess the impact of small water conservation structures over discharge and sediment yield which helps in developing the part of rural areas which are affected by soil erosion and floods. Jonk watershed, which is a tributary of Mahanadi basin, has been selected as study area. The model has been run for two case scenarios i.e. watershed with pond as conservation structures and watershed without ponds or any conservation structure. The study has been carried out for the year 2001. However more emphasis was given to the monsoon season.

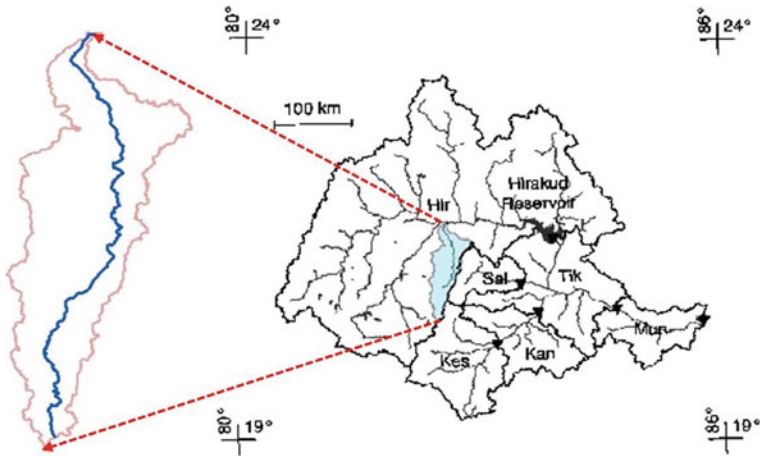


Fig. 1 Jonk watershed

## 2 Study Area

The Jonk watershed lies between geographic latitude  $20^{\circ} 28'$  and  $21^{\circ} 44'N$  and longitudes  $82^{\circ} 20'$  and  $83^{\circ} 00'E$  (Fig. 1). The river Jonk originates from Nuapada district of Orissa at an elevation of 700 m from MSL. It merges with Seorinarayan, upstream of Hirakud Dam after travelling the distance of 182 km having a drainage area of  $3424 \text{ km}^2$ .

The climate of the area is characterized by hot summer except during south-western monsoon. The watershed receives about 90% of the rainfall during monsoon which is active from middle of June to the end of September. Normal minimum temperature is  $10^{\circ} \text{C}$  and maximum temperature is  $43^{\circ} \text{C}$  (CWC). Geologically, the watershed consists of gneiss rock formation. The sub-basin comprises of alluvial formation of various thickness.

## 3 Materials and Methods

Soil and Water Assessment Tool (SWAT) is a semi-distributed, partially physically based, data driven model and requires several types of data such as rainfall, temperature, land use, soil, wind velocity, etc. [6]. Data has been collected from various sources and carried out post-processing processes on the datasets. The methodology of the study is presented in Fig. 2.

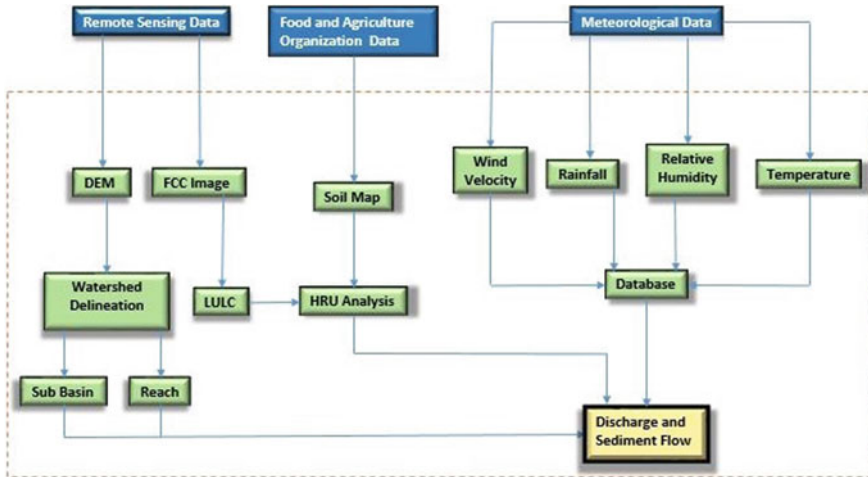


Fig. 2 Methodology for estimating discharge and sediment flow

### 3.1 Land Use Database

False color composite (FCC) image of Landsat 8 (dated: 9th Nov 2013) has been used for this study. The image was re-projected to UTM 44 N projection using ArcGIS software. The land use map has been derived using maximum likelihood method under supervised classification by using ERDAS Imagine software.

### 3.2 Soil Database

Soil dataset has been obtained from Food and Agriculture Organisation (FAO) [3]. The necessary input information required by the SWAT model was extracted from the same database for each soil type, namely soil texture, Hydrological Soil Group (HSG).

### 3.3 Weather Database

SWAT requires daily values for precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed for modeling of various physical processes, soil and rainfall being the most important. Daily meteorological data was collected from India Meteorological Department (IMD).

### 3.4 SWAT Project

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Map (DEM) of 30 m resolution has been used for this study. DEM was converted from geographic coordinate system to projected coordinate system (UTM, datum: WGS84). The processed DEM has been imported to SWAT project to start watershed delineation. After importing to SWAT project, streams are defined based on the drainage area threshold. The outlet for the whole watershed has been defined near Rampur for delineation of watershed boundary. The watershed sub basin parameters are calculated with locating the positions of the reservoirs. For each sub basin land use data and soil data are defined. As the runoff depends on the actual hydrologic conditions of each land cover and soil present in the watershed, therefore impact of each landuse is considered. Hydrologic response unit (HRU) is defined as 20% for landuse, slope and soil class for each sub basin. One of the main sets of input for simulating the watershed in SWAT is climate data. Climate inputs consist of precipitation, maximum and minimum temperature, solar radiation, wind speed and relative humidity. The daily precipitation records of 2001 were used which were analyzed to develop the climate-input files required for the model. After addition of all the above data, the SWAT model is set up and run on the basis of daily and monthly simulation. In this case study, the main emphasis is on the reduction of discharge and sediment flow in the Jonk watershed by addition of ponds as water conservation structures. In SWAT, runoff volume is estimated from daily rainfall using the modified SCS-CN (Curve Number Method) and Green-Ampt methods. The SCS-CN equation is:

$$Q_{\text{surf}} = \frac{(R_{\text{day}} - I_a)^2}{(R_{\text{day}} - I_a + S)} \quad (1)$$

where,  $Q_{\text{surf}}$  is accumulated runoff,  $R_{\text{day}}$  is rainfall depth for the day,  $I_a$  is the initial abstractions commonly taken as  $(0.2 * S)$ ,  $S$  is the retention parameter which is given as

$$S = \left( \frac{25,400}{\text{CN}} \right) - 245 \quad (2)$$

The discharge is calculated with the help of rational formula which is written as:

$$Q_{\text{peak}} = \frac{C * i * A}{3.6} \quad (3)$$

where,  $Q_{\text{peak}}$  is the peak runoff rate ( $\text{m}^3/\text{s}$ ),  $i$  is the rainfall intensity ( $\text{mm}/\text{hr}$ ),  $C$  is the runoff coefficient,  $A$  is area of the sub basin ( $\text{km}^2$ ) and 3.6 is the unit conversion factor.

Similarly, the sediment flow is obtained from the Modified Universal Soil Loss Equation (MUSLE) which is given as:

$$\text{Sed} = 11.8 * (Q_{\text{surf}} * Q_{\text{peak}} * \text{area}_{\text{hru}}) 0.56 * \text{KUSLE} * \text{LSUSLE} * \text{CUSLE} * \text{PUSLE} * \text{CFRG} \quad (4)$$

where, Sed is the sediment yield on given day (metric tons),  $Q_{\text{surf}}$  is the surface runoff volume (mm/ha),  $Q_{\text{peak}}$  is the peak runoff rate ( $\text{m}^3/\text{s}$ ),  $\text{area}_{\text{hru}}$  is area of HRU (ha), KUSLE is the USLE soil erodibility factor, LSUSLE is the USLE topographic factor, CUSLE is USLE cover and management factor, PUSLE is USLE land practice factor, CFRG is coarse fragmentation factor.

Here, the SWAT model has been run for the total 20 ponds (Table 1) in the villages that fall in the buffered area of 2 km on both sides from the centre line of the river (Fig. 4).

**Table 1** Location of ponds in villages

Name	Longitude (°E)	Latitude (°N)
Pond 1	82.65	21.14
Pond 2	82.64	21.43
Pond 3	82.61	21.44
Pond 4	82.57	21.56
Pond 5	82.60	21.51
Pond 6	82.65	21.36
Pond 7	82.66	21.28
Pond 8	82.61	21.24
Pond 9	82.62	21.08
Pond 10	82.61	20.99
Pond 11	82.58	21.00
Pond 12	82.49	20.90
Pond 13	82.46	20.82
Pond 14	82.46	20.81
Pond 15	82.41	20.75
Pond 16	82.43	20.75
Pond 17	82.51	20.90
Pond 18	82.62	21.31
Pond 19	82.67	21.36
Pond 20	82.53	21.59

### 4 Results and Discussion

A physically based SWAT model has been used for assessment of the impact of small water conservation structures on hydrology of a watershed and the results obtained are quite satisfactory. Figures 3, 4, 5, 6, 7 and 8 shows the maps of River centre line buffer area, LULC, Slope, Drainage network, Hydrologic response unit and Soil respectively. The results obtained are for the period of July to October i.e. from pre-monsoon to post- monsoon period. The annual mean reduction of the discharge due to pond construction is found to be 69.27% while mean reduction in

Fig. 3 Jonk river centreline buffer map

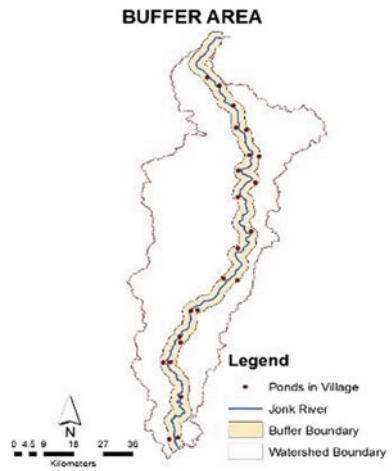


Fig. 4 Land use and land cover map

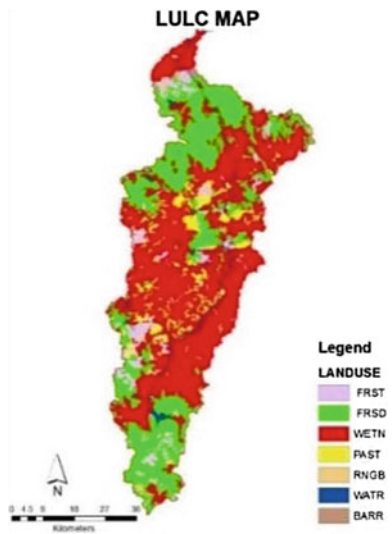


Fig. 5 Slope map

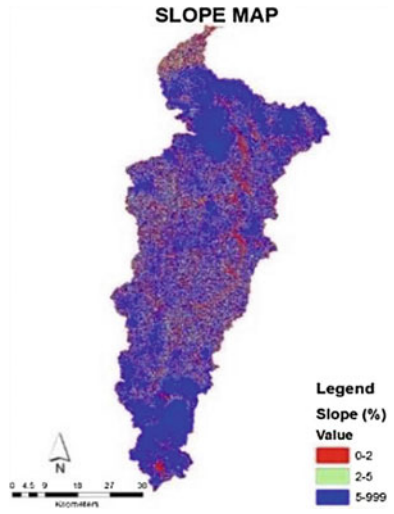
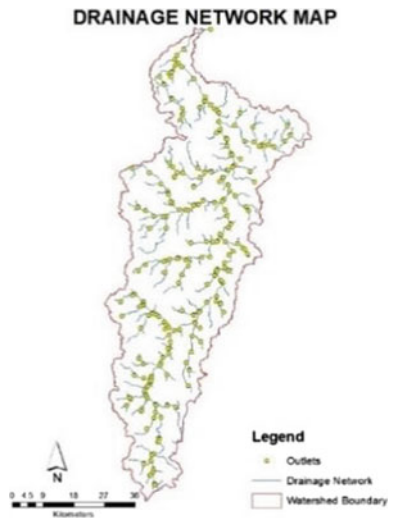


Fig. 6 Drainage network map



sediment flow due to construction of pond is found to be 64.10%. From the above study, it can be concluded that construction of small water conservation structures can be very helpful in controlling the discharge which can cause floods and controlling the sediment flow which causes the sedimentation of the reservoirs. The maximum daily discharge and sediment flow in Jonk watershed is found to be 2.97 cumecs and  $1.937 \times 10^5$  t/ha/yr respectively for the year 2001 when there was no pond as water conservation structures and the same is reduced to 1.984 cumecs and  $0.29 \times 10^5$  t/ha/yr due to presence of pond (Figs. 9 and 10). The maximum monthly discharge and sediment flow is also observed to be decreased from 2.13 to



**Fig. 7** Hydrologic response unit map



**Fig. 8** Soil map



1.25 cumecs and  $5.05 \times 10^5$  to  $1.22 \times 10^5$  t/ha/yr respectively due to addition of pond as water conservation structures (Figs. 11 and 12). The comparison of different parameters with the both case scenarios is shown in Table 2. The reduction in monthly discharge due to addition of water pond as water conservation structure is found to be 41–89%. The reduction in monthly sediment flow due to addition of

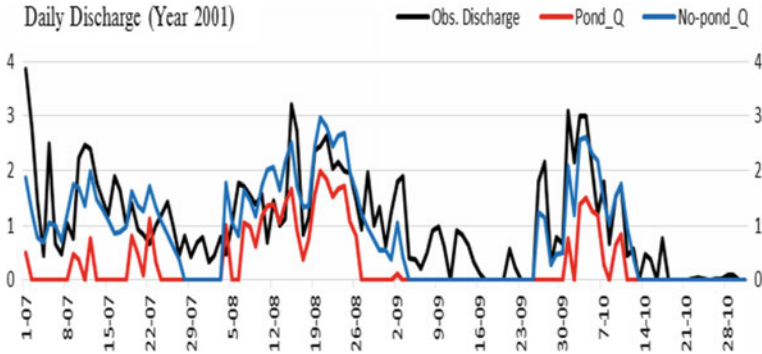


Fig. 9 Plot of observed and simulated daily discharge (cumecs) in two scenarios

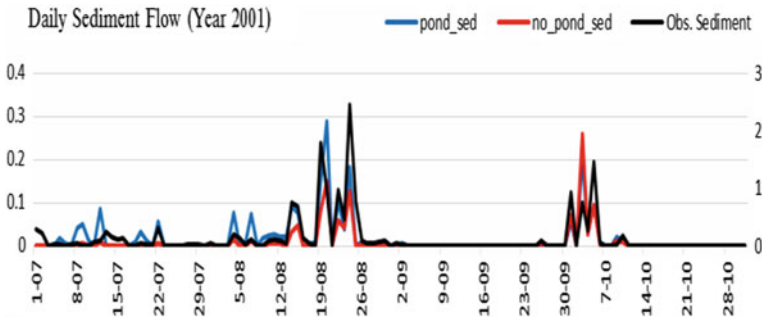


Fig. 10 Plot of observed and simulated daily sediment flow (t/ha/yr) in two scenarios

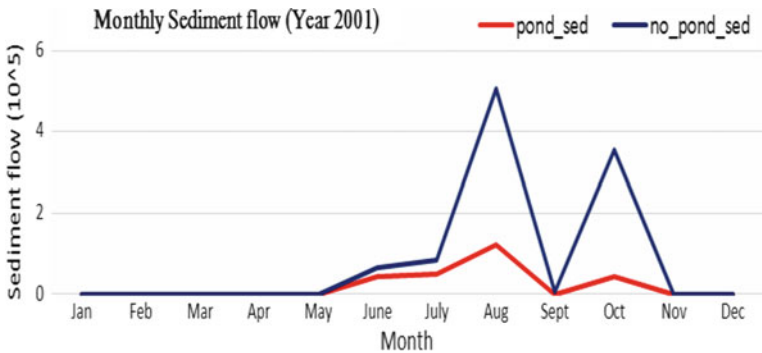
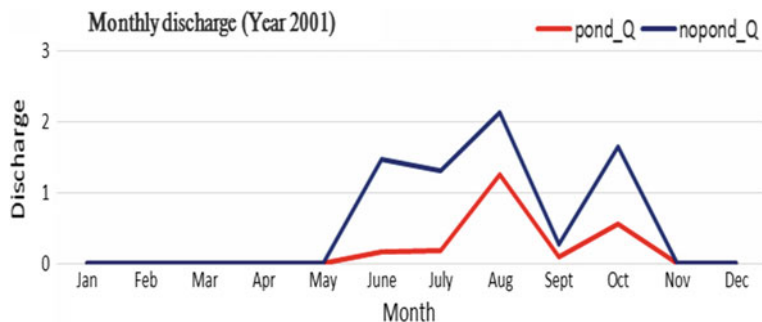


Fig. 11 Plot of simulated monthly sediment flow (t/ha/yr) in two scenarios

water pond as water conservation structure is found to be 32–88%. Due to addition of the water structure, the flow of sediment is reduced which results in less soil erosion also the capacity of reservoir will increase. Deposit of sediments will



**Fig. 12** Plot of simulated monthly discharge (cumeecs) in two scenarios

**Table 2** SWAT model standard output

Hydrological parameters	Scenario 1 (without pond)	Scenario 2 (with pond)
Precipitation (mm)	768.7	768.7
Lateral soil runoff (mm)	29.00	30.00
Shallow aquifer runoff (mm)	0.00	0.20
Deep aquifer runoff (mm)	0.20	0.90
Deep aquifer recharge (mm)	0.40	1.60
Total aquifer recharge (mm)	7.60	31.30
Total water yield (mm)	106.70	130.40
Percolation out of soil (mm)	7.85	32.35
Total sediment loading (t/ha)	1.50	1.45

increase the percolation of the water in the ground, which results increase in ground water recharge in and around the 20 rural areas. This is a good sign for the population in terms of quality of life and development of the region.

## 5 Conclusion

The study of Jonk watershed area using the SWAT model is reliable for estimation of monthly discharge and sediment flow. The simulated discharge and sediment flow data has been compared with the observed data and the correlation coefficient is found to be 0.84 & 0.77 respectively. The annual discharge and sediment flow value in “with pond scenario” has been detected to be reduced by 69.27 and 64.10% respectively. The results observed in the present work can be used for site suitability analysis of soil and water conservation structures in the areas those are prone to soil erosion and floods. The study also reveals that the applications of GIS and Geospatial Data Management can be used efficiently for watershed management and rural development.

## References

1. Bhuyan, S.J., Koelliker, J.K., Marzen, L.J., Harrington, J.R.: An integrated approach for water quality assessment of Kansas watershed. *Environ. Model Softw.* **18**, 473–484 (2003)
2. Fan, M., Shibata, H.: Simulation of watershed hydrology and stream water quality under landuse and climate change scenarios in Teshio River watershed, northern Japan. *Ecol. Indic.* **50**, 79–89 (2015)
3. FAO: United Nations Food and Agriculture Organization, Soil Map of the World, vols. 1–10 (1:5 M scale maps). UNESCO, Paris (1981)
4. Gassman, P.W., Reyes, M.R., Green, C.H., Arnold, J.G.: The soil and water assessment tool: historical development, applications, and future research directions. *Trans. ASABE* **50**(4), 1211–1250 (2007)
5. Guo, H., Hu, Q., Jiang, T.: Annual and seasonal streamflow responses to climate and land-cover changes in the Poyang Lake basin, China. *J. Hydrol.* **355**(1), 106–122 (2008)
6. Nasrin, Z., Sayyad, G.A., Hosseini, S.E.: Hydrological and sediment transport modelling in maroon dam catchment using soil and water assessment tool (SWAT). *Int. J. Agron. Plant Prod.* **4**(10), 2791–2795 (2013)
7. Nie, W., Yuan, Y., Kepner, W., Nash, M.S., Jackson, M., Erickson, C.: Assessing impacts of landuse and landcover changes on hydrology for the upper San Pedro watershed. *J. Hydrol.* **407**(1), 105–114 (2011)
8. Singh, V.P., Frevert, D.K.: Mathematical modelling of watershed hydrology. Chapter 1, in: *Mathematical Models of Small Watershed Hydrology and Applications*, Water Resources Publications, Littleton, Colorado, pp. 1–3 (2002)
9. Zhou, F., Xu, Y., Chen, Y., Xu, C.Y., Gao, Y., Du, J.: Hydrological response to urbanization at different spatio-temporal scales simulated by coupling of CLUE-S and the SWAT model in the Yangtze River Delta region. *J. Hydrol.* **485**, 113–125 (2013)