Rainfall-runoff modelling of Ajay river catchment using SWAT model

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Abstract. The present study is based on SWAT (Soil and Water Assessment Tool) Model which integrates the GIS information with attribute database to estimate the runoff of Ajay River catchment. Soil and Water Assessment Tool (SWAT) is a physically based distributed parameter model which has been developed to predict runoff, erosion, sediment and nutrient transport from agricultural watersheds under different management practices. The SWAT Model works in conjunction with Arc GIS. In the present study the catchment area has been delineated using the DEM (Digital Elevation Model) and then divided into 19 sub-basins. For preparation of landuse map the IRS-P6 LISS-III image has been used and the soil map is extracted from HWSD (Harmonized World Soil Database) Raster world soil map. The sub basins are further divided into 223 HRUs which stands for Hydrological Response Unit. Then by using 30 years of daily rainfall data and daily maximum and minimum temperature data SWAT simulation is done for daily, monthly and yearly basis to find out Runoff for corresponding Rainfall. The coefficient of correlation (r) for rainfall in a period and the corresponding runoff is found to be 0.9419.

Keywords: Runoff; Rainfall; SWAT;

1. Introduction
In water resources studies runoff is the most important hydrological variables used. Estimation of direct runoff for ungauged river basins is difficult and time consuming. The conventional models for predicting runoff requires considerable hydrological and meteorological data. Many models were developed for watershed hydrology but the availability of temporal and spatial data was the main constraint hindering the implementation of these models especially in developing countries. Remote sensing and Geographic Information Systems (GIS), in combination with appropriate rainfall runoff models, provide ideal tools for the estimation of direct runoff volume, peak discharge and hydrographs. However, the development of remote sensing techniques and Geographic Information System (GIS) capabilities has influenced and enhanced the vast use of these models worldwide.

The model will be capable of forecasting the runoff for any given event of rainfall for the required duration. ERDAS IMAGINE 9.1, ArcGIS 10 and ArcSWAT2012 are the main software used in the present study. In the present study an attempt has been made for estimation of runoff using SWAT model utilizing GIS.

2. Study area
The present study area taken is the catchment of Ajay River. The river Ajay takes its rise from the eastern fringe of the Chotanagpur the Chotanagpur Plateau in Munger District of Bihar and after traversing the Gneissic terrain for a length of 162 km. Figure 1 shows the location map of the Ajay river catchment.
It encounters the Gondwana sedimentary of the Raniganj-Andal Coalfields. Subsequently it flows over the alluvial tract of the Bengal basin area. For the rest of the course up to the confluence point with the Bhagirathi at Katwa in West Bengal. It is a major river in Jharkhand and West Bengal. Total length of the Ajay is 288 km, out of which 152 km is in West Bengal. The catchment area of Ajay River is 5813.75 km². The important tributaries of the Ajay are Pathro and Jayanti in Jharkhand and Tumuni and Kunur in Bardhaman district of West Bengal. The study area latitudinally extends from 23°26’ N to 24°35’ N and longitudinally between 86°16’ E to 88°10’ E.

3. Description of SWAT model

Soil and Water Assessment Tool (SWAT) is a physically based distributed parameter model which has been developed to predict runoff, erosion, sediment and nutrient transport from agricultural watersheds under different management practices. The SWAT works in conjunction with ArcGIS with an extension ArcSWAT a graphical user interface for SWAT tool. The hydrologic cycle as simulated by SWAT is based on the water balance equation (1). Here the runoff volume is estimated by using the Soil Conservation Service (SCS) curve number technique (USDA, 1972).

\[
SW_t = SW_0 + \sum_{i=1}^{t} \left( R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw} \right)
\]

Where, \(SW_t\) is the final soil water content (mm H2O), \(SW_0\) is the initial soil water content (mm H2O), \(R_{day}\) is amount of precipitation on day \(i\) (mm H2O), \(Q_{surf}\) is the amount of surface runoff on day \(i\) (mm H2O), \(E_a\) is the amount of evapotranspiration on day \(i\) (mm H2O), \(w_{seep}\) is the amount of percolation and bypass exiting the soil profile bottom on day \(i\) (mm H2O), \(Q_{gw}\) is the amount of return flow on day \(i\) (mm H2O).

For simulation, a watershed is sub-divided into a number of sub-basins or sub watersheds. 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. The total runoff mainly depends on the actual hydrologic condition of each land cover soil type and slope present in the watershed. Therefore, the impact of each type of land use is considered in this modelling to calculate runoff of the basin. After the overlay of the land-use, soil maps and slope, the distributions of the Hydrological Response Units (HRUs) were determined. HRUs divide the sub basin in to the area of similar land use, soil type and slope. Runoff is predicted separately for each HRU and routed to
obtain the total runoff of the watershed. This increases accuracy and gives a much better physical description of the water balance.

4. Methodology
SWAT requires many sets of spatial and temporal input data. As a semi-distributed model, SWAT has to process, combine and analyze spatially these data using GIS tools. Therefore, to facilitate the use of the model, it was coupled with GIS software as a free additional extension ArcSWAT for ArcGIS. The methodology for the runoff modelling at the basin outlet using SWAT is depicted in flow chart Figure 2.

4.1 Digital elevation model (DEM)
DEM (Figure 3a) is extracted from the website of NASA. It is used to delineate the watershed and sub-basins as the drainage surfaces, stream network and longest reaches. The topographic parameters such as terrain slope, channel slope or reach length were also derived from the DEM.

4.2 Land use map
Land use/land cover map (Figure 3b) for the study area is prepared using satellite IRS-P6 LISS-III image (acquired on January 2006) with spatial resolution of 23 m. The Supervised classification technique has been carried out to derive and distinguish the most present land use classes in the Ajay basin. Eight major classes were so identified. The dominant categories are fallow land (66.31%) and water (22%) and urbanized areas (4%). The forest and agriculture represent 2% and 1% of the watershed respectively.

4.3 Soil map
The soil map is extracted from the Harmonized World Soil Database (HWSD) raster world soil map. In the context of a complete update of the global agro-ecological zones study, FAO and IIASA combined existing regional and national updates of soil information worldwide and incorporated these with the information contained within the 1:5,000,000 scales FAO-UNESCO Soil Map of the World (FAO, 1971-1981). There are six types of textural classes present in the study area. The complete soil map is shown in Figure 3c.

4.4 Hydro-meteorological data
SWAT requires daily values for precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed for modeling of various physical processes. Rainfall data and Temperature data of Ajay river catchment has been downloaded from Indian Meteorological Department, Pune and http://swat.tamu.edu respectively. Here 30 years of 0.5 degree gridded daily rainfall data and also 30 years of 1 degree gridded daily maximum and minimum temperature data is used from the year 1976 to 2005 in this study area. The location map of the raingauge stations as well as temperature stations has been shown in Figure 3d.

Figure 2. Methodology for rainfall-runoff modelling.
Figure 3. Spatial and weather data of the study area (a) DEM (b) Landuse Map (c) Soil Map (d) Location of weather stations.

5. Model setup
The entire database required by the SWAT model is developed for the study area and the model has been setup. ArcSWAT2012 allows us to delineate sub-watersheds based on an automatic procedure using DEM. DEM is imported in the model and the mask is manually created in the model in order to extract out the ajay sub-catchment area. The outlet is defined for the catchment area and Watershed was delineated for the present study (Figure 4.) and all the parameters are calculated for each sub basins. The total area of the catchment is found to be 5813.75 km². The minimum and maximum elevations of the study area are 0 m and 705 m respectively. The catchment is divided into 19 sub-basins. SWAT allows us to import the land use and soilmap to the model, then evaluate slope characteristics and determine the land HRUs for each sub-watershed. Land use category is used for specifying the land use layer and soil look up table is used for specify the type of soil to be modeled for each category. The soil map reclassified the database in 4 hydrological soil group (HSG) named A, B, C and D based on their infiltration rate. The LULC map is also reclassified into 8 different categories. The slope map is reclassified in 5 classes i.e. 0-3%, 3-8%, 8-20%, 20-45% and above 45%. Next the land use, soil and slope data layers have been overlaid. The distribution of hydrologic response units (HRUs) within the catchment has been determined. A total of 223 HRUs were generated in the Ajay
river catchment. To eliminate minor land use, soil and slope, a threshold percentage of 10% has been adopted for all the land use, soil and slope classes.

![Watershed Delineation Map](image)

**Figure 4.** Delineation of sub-basins of Ajay catchment.

The model requires daily data for precipitation and temperature. SWAT allows the user to load weather station locations into the current project and assign weather data to the sub-watersheds. Here 30 years (1976 to 2005) daily rainfall data for 9 raingauge stations and daily maximum and minimum temperature data for 5 stations the same years has been utilized. Weather data is loaded using the ‘Write Input Tables’ menu on the ArcSWAT toolbar. This tool allows user to load weather station locations into the current project and assign weather data to the sub-watersheds. For each type of weather data loaded, each sub-watershed is linked to one gauge. Before SWAT can be run, the initial watershed input values must be defined. These values are set automatically based on the watershed delineation and Land use\ soil\ slope characterization or from defaults. After this step, the model was run to simulate the surface runoff.

6. **SWAT simulation**

The SWAT Simulation menu allows user to finalize the setup of input for the SWAT model and run the SWAT model, perform sensitivity analysis and perform auto-calibration.

7. **Results and discussions**

This study shows the structure of the SWAT-based model used in modeling of the Rainfall Runoff process. SWAT simulation is done for daily, monthly and yearly basis. Average runoff for average yearly rainfall is shown in Figure 5 from which it can be seen that the maximum runoff occurred in the year 1984. The rainfall runoff correlation has also been done for 30 years data and a good correlation is found with r² value 0.8872.

SWAT also gives daily Runoff for corresponding daily Rainfall value throughout the year. Here the graphical representation of daily maximum Rainfall-Runoff values for each year for 30 years period has been shown in Figure 6.

8. **Conclusions**

SWAT model for the catchment produced good simulation results for daily, monthly and yearly runoff values as for the other water balance components. In this context, the observed correlation coefficient(r) is 0.9419. The evaluation of the model performance was carried out successfully with
the recommended statistical coefficients. These performances can be enhanced furthermore using more accurate input data especially for the soil, landuse and DEM data that were estimated in this study with global data. The integration of climatic data such as rainfall data, temperature data also helps to compute accurate rainfall-runoff correlation. With the help of observed runoff data of the catchment, model validation can be done.

Figure 5. Yearly average Rainfall-Runoff.

Figure 6. Daily Maximum Rainfall-Runoff.
9. References

[1] Khare D, Singh R and Shukla R 2014 Int. J. of Geology, Earth & Environmental Sciences 4 (1) 224-235
[2] Singh V, Bankar N, Salunkhe S S, Bera A K, and Sharma J R 2013 CURRENT SCIENCE, 104(9) 1187
[3] Winchell M, Srinivasan R, Luzio M D, and Arnold J 2013) “ArcSWAT Interface For Swat2012”
[4] Fadil A, Rhinane H, Kaoukaya A, Kharchaf Y and Bachir O A 2011 J. of Geographic Information System 3 279-289
[5] Easton Z M, Fuka D R, White E D, Collick A S, McCartney A, Biruk B, Awulachew M, Ahmed S B and Steenhuis T S, 2010 Hydrol. Earth Syst. Sci. 14 1827–41
[6] Simić Z, Milivojević N, Prodanović D, Milivojević V and Perović N 2009 J. of the Serbian Society for Computational Mechanics 3(1) 38-63
[7] Setegn S G, Srinivasan R, and Dargahi B 2008 The Open Hydrology Journal 2 49-62
[8] Arnold J G and Fohrer N 2005 Hydrol. Process. 19 563–572
[9] Singh V P and Woolhiser D A 2002 Journal of Hydrologic Engineering 7(4) 270-292
[10] Chong Y X 2002 “TEXT BOOK OF HYDROLOGIC MODELS”, Uppsala
[11] Bellal M, Sillen X, Zeck Y, 1996 (Proceedings of the Vienna Conference, April 1996
[12] Kovar K, Nachtnebel H P Int. Association of Hydrological Sciences, Series of Proceedings and Reports, 235 99-106
[13] Miloradov M, Marjanovic P, 1991 3rd Rhine-Danube Workshop Proceedings