Micro Watershed Modeling in India Using GIS Technologies and Agricultural Policy Environmental Extender (APEX) Model. A Case Study

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ABSTRACT
Study demonstrates the application of GIS technologies and APEX model for watershed management in Salasi watershed, Himachal Pradesh India. Extensive processing of static and dynamic data for the study area were performed using GIS technologies for use in APEX model. DEM for the study area was generated using extrapolated contours taken from 1:50,000 scale Survey of India topographic map. Satellite interpreted data for the land use and digitized soil map using NBSSLUP soil map with a resolution of 1:500,000 were used to prepare the land use and soil input files for APEX model run. To know the flow direction and topographic information required to build the Subarea file of APEX, the automatic delineation of watersheds was done by using the DEM as input to AVSWAT model. The target outflow point is interactively selected. A threshold value of 25 ha has been used for generating the stream network which primarily decides the density of the stream network and consequently the number of sub basins. With this setup model was run successfully but the results could not be tested against the observed flow due to unavailability of data on observed flow for the study area. However the trend in simulated daily flow followed the trend in observed rainfall which indicate that the framework can be used to model the relative changes in flow component under different conservation practices as compared to this base run.
Key Word: SWAT, APEX, GIS, Subbasin, Flow

I. Introduction

A watershed model simulates hydrologic processes in a more holistic approach, compared to many other models which primarily focus on individual processes or multiple processes within a water body without full incorporation of watershed area (Oogathoo, 2006). Advances in the understanding of physical, chemical, and biological processes influencing water quality and quantity, coupled with improvements in the collection and analysis of hydrologic data, provide opportunities for significant innovations in the manner and level with which watershed-scale processes may be explored and modeled. The utility of hydrological modeling for generation of crucial information such as water and sediment yield for planning and management of the watershed management program is being increasingly recognized now. A number of simulation models have been developed to evaluate water quantity and quality parameters affected by agricultural land management at both field and watershed scale. Widely used Watershed scale models include storm event based AGNPS (Agricultural Non-Point Source Pollution Model) and continuous daily time step model SWRRB (Simulator for Water Resources in Rural Basins). Expansion of SWRRB model's capacities to facilitate more sub-basins and sophisticated routing structure resulted in a new watershed scale model SWAT (Soil and Water Assessment Tool) (Arnold et al., 1998). Widely used field scale models include CREAMS (Chemicals, Runoff, Erosion from Agricultural Management Systems), EPIC (Erosion-Productivity Impact Calculator), and GLEAMS (Groundwater Loading Effects of Agricultural Management System). Expansion of EPIC model capability to simulate multi field routing for use in whole farm/small watershed management resulted in the development of APEX (Agricultural Policy/Environmental Extender) (Williams and Izaurralde, 2006).

The utilization of GIS technology in watershed modeling has brought great value and presents future potential benefits for watershed managers. To date, watershed modelers have been able to capture the key hydrological behaviors of many watershed systems. Despite the complexity and uncertainty of various watershed processes, many engineering-based models have been successfully calibrated, verified, and applied by decision makers. Our ability to model hydrologic processes with greater accuracy, and at finer spatial and temporal resolution, continuing to improve with increased use of remotely sensed data (e.g., satellite observations), increased computational capacity and improvements in GIS and database management systems and availability of meteorological information for simulating the water balance components. In India GIS based SWAT model has been widely tested and recognized as reliable tool for watershed management at watershed level (Gosain et al, 2004, Gosain et al., 2005). However implementation of SWAT at micro watershed or filed level is not yet completely tested with greater degree of confidence. APEX model (Williams and Izaurralde, 2006) is now increasingly applied in different part of world to simulate the impact of different conservation practices at plot level (Wang et al., 2006; Saleh et al., 2007, Santhi et al., 2008). In the present study an attempt has been made to prepare a GIS based modeling framework for application of APEX model for watershed management in Salasi watershed of Hamirpur, Himachal Pradesh. Details methodology and data used for the purpose is described in the following section.

II. Materials and Methods

2.1. Modeling Tools

The hydrological models have an important role in generating the water balance components through simulation using the easily available information of the inputs of meteorological parameters. The SWAT model adopted for the purpose along with the APEX model being adopted for the cadastral level have been described below.

2.1.1. The SWAT Model

The SWAT model is a basin-scale distributed hydrologic model. It was developed to quantify the impact of land management practices in large, complex catchments (Arnold et al., 1998). SWAT is capable of accepting output data from other simulation models. SWAT operates on a daily time step and allows a basin to be divided into subbasins based on topography to incorporate spatial details. Each subbasin is further divided into hydrological response units (HRUs), which are unique combinations of soil and land cover. Individual HRUs are simulated independently, area weighted, and added for each subbasin and then routed through a stream network to the basin outlet. HRUs allow more spatial detail to be included by representing more land use and soil classifications in the landscape in a computationally efficient manner. The HUMUS project (Srinivasan et al., 1998) used SWAT to model 350 USGS 6-digit watersheds in the 18 major river basins in the U.S. The revised HUMUS/SWAT (Santhi et al., 2005) modeling framework with updated databases for the 18 major river basins was used for the CEAP cropland national assessment,in which the cultivated cropland and CRP land are simulated using the APEX model. The reason for applying SWAT model in present study has been two folds. The first one is to GIS interface of the SWAT to carry out the automatic delineation at the watershed level which is not available in the APEX, and the second one is that this shall give opportunity to evaluate the impact of bringing the natural areas under cultivation on its hydrology.

2.1.2. The APEX Model

The APEX model is an integrated dynamic tool that is capable of simulating extensive land management strategies, such as nutrient management practices, tillage operations, and alternative cropping systems on the field, farm, or small watershed scale. It can be configured to simulate filter strip impacts on pollutant loss from upslope fields, intensive rotational grazing scenarios depicting movement of cows between paddocks, impacts of vegetated grassed waterways in combination with filter strip, land application of manure, as well as removal of manure from livestock feedlots or waste storage ponds (Gassman et al., 2010). APEX operates on a daily time step. A detailed theoretical description of APEX can be found in Williams and Izaurralde (2006). The APEX model was selected for the CEAP field-level cropland modeling due to its flexibility and features. For example, field units within APEX have spatial relationships and can be routed at the field scale, which provides for physically based simulation of conservation practices such as filter strips, terraces, and waterways. In addition, the APEX crop growth component enables simulation of mixed stands with plant competition for light, water, and nutrients. APEX also simulates detailed management practices related to farm animal production, rotational grazing, and wind erosion. APEX enables dynamic soil layers associated with soil erosion and removal of eroded material, and it provides eight options (including RUSLE 2) for estimating water erosion. APEX simulates tillage with the functions for mixing nutrients and crop residue, converting standing residue to flat residue, changing bulk density and subsequent settling after tillage, and speeding mineralization. APEX features an improved soil carbon cycling routine that follows the Century model (Parton et al., 1994; Vitousek et al., 1994). APEX has also manure management with automatic application from a stockpile or a lagoon, and simulates manure erosion from feedlots and application fields. APEX has its own data bases for weather simulation, soils, crops, tillage, fertilizer, and pesticides. Convenient interfaces are available for assembling inputs and interpreting outputs

2.2 Application of APEX Model

2.2.1. Study Area

Three sub watersheds (Chabuta Nala, Amroh Nala and Kuthera Nala) falling under the Salasi Khad watershed in Hamirpur development block in Hmirpur district of Himachal Pradesh, India have been considered in this study. These micro watersheds are situated between 76°18’ to 76°44’ East longitude and 35°52’, 35°30’ North latitude. They are located at a distance of 14 KM from

Sujanpur development block and KM from district headquarter, along the state highway connecting Hamirpur and Nadaun. Rain-fed agriculture is the primary land use in these watersheds with a small percentage under irrigation. Mixed cropping is generally practiced in this area, with wheat and maize being the predominant crops. At some places paddy is also grown. Maize is usually cropped with pulses and wheat mixed with "Sarson".

2.2.2. Input Data

The following data have been made use of under the static and dynamic categories of data.

2.2.2. 1. Static Data

- Contours 1:50,000 SOI
- Drainage Network (Same scales as above)
- Rain gauge and meteorological stations and their locations (Latitude, Longitude)
- Soil maps and associated soil characteristics (1:500,000)
- Land use

2.2.2. 2. Dynamic Data

- Meteorological Data (Quantitative daily data on rainfall, maximum and minimum temperature, relative humidity and wind speed for the period from 1998 to 2002).

2.2. 3. Pre–Processing of input Data

All the above data has been processed in the form of digitization and putting the same together in a geo-referenced form to create the base for the potential framework..

2.2.3.1. Contour Theme

1:50,000 SOI toposheets belonging to Salasi Khad were digitized to generate contours. The elevation as attribute was duly attached to the contour layer. Figure 1 depicts the contours and the inset shows the closer interval contours.

Figure 1: Contours at 20 m interval falling within the Study Area

2.2.3.2. Digital Elevation Model (DEM)

DEM generated using extrapolated contours taken from 1:50,000 scale SOI topographic map of the study area is shown in Figure 2

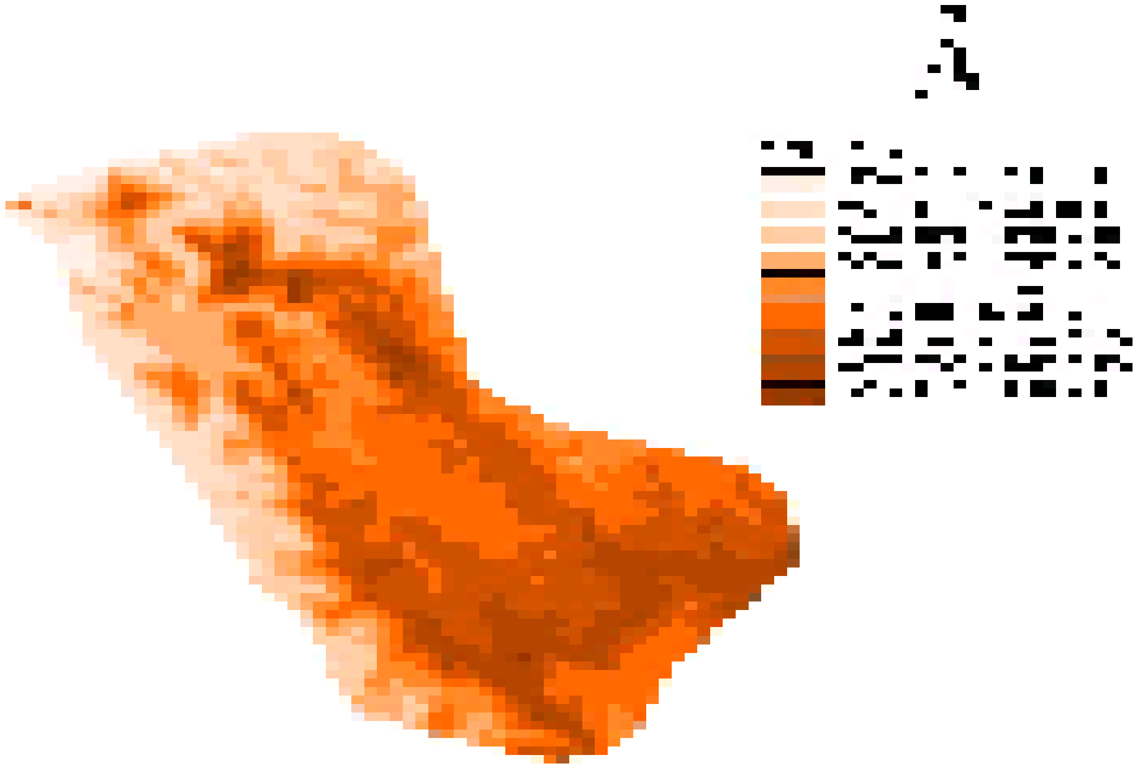

Figure 2: Digital Elevation Model (DEM)

2.2.3.3 Land Cover/Land Use Layer

Satellite interpreted data for the land use is used for the study. Figure 3 shows the broad land use categories which are used for the initial model setup

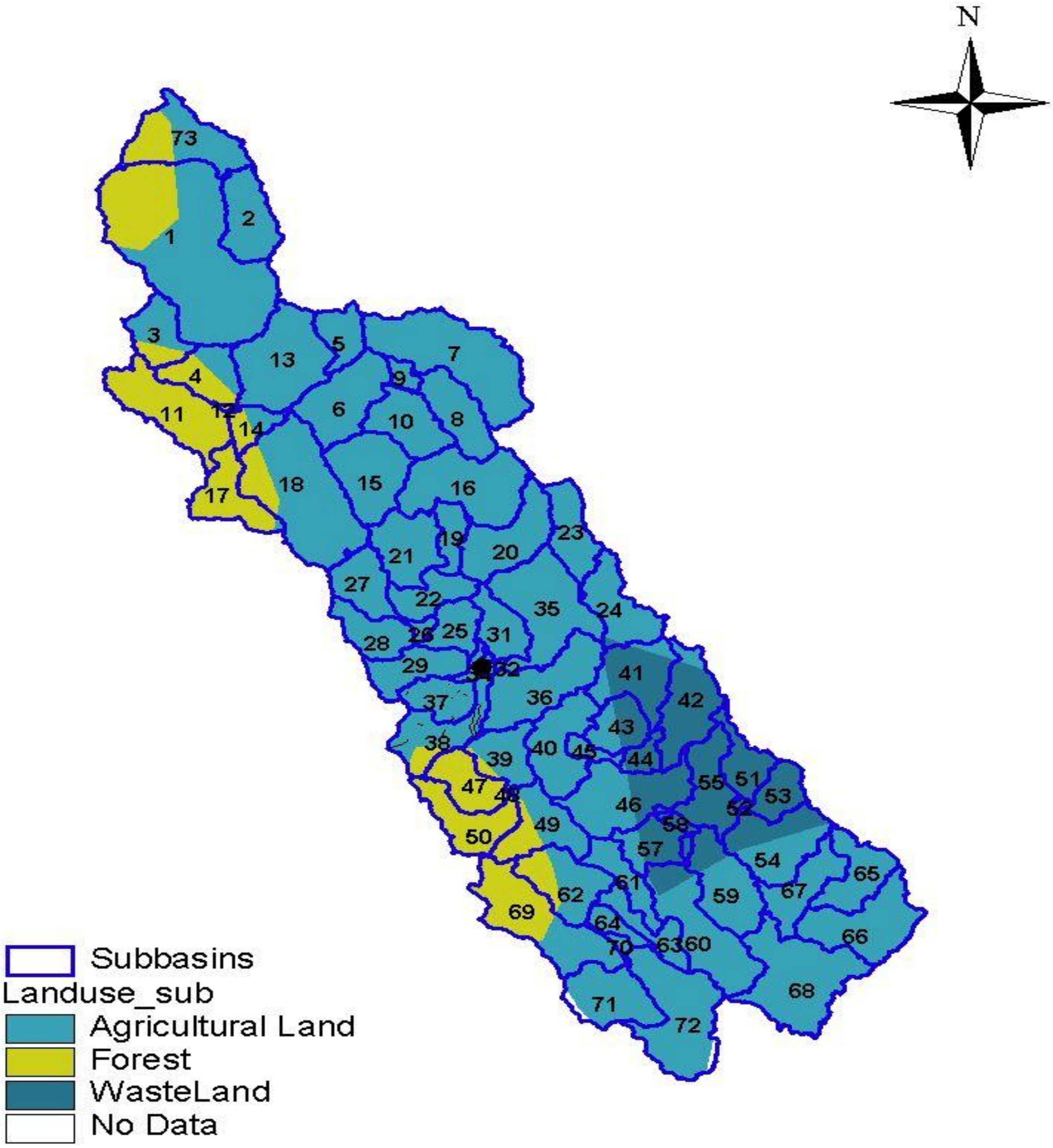

Figure 3: Land use classification for Salasi watershed

2.2.3.4. Soil Layer

Soil map was digitized using NBSSLUP soil map with a resolution of 1:500,000. The soil map is shown in Figure 4. A sample Soil units details are given in Table 1.

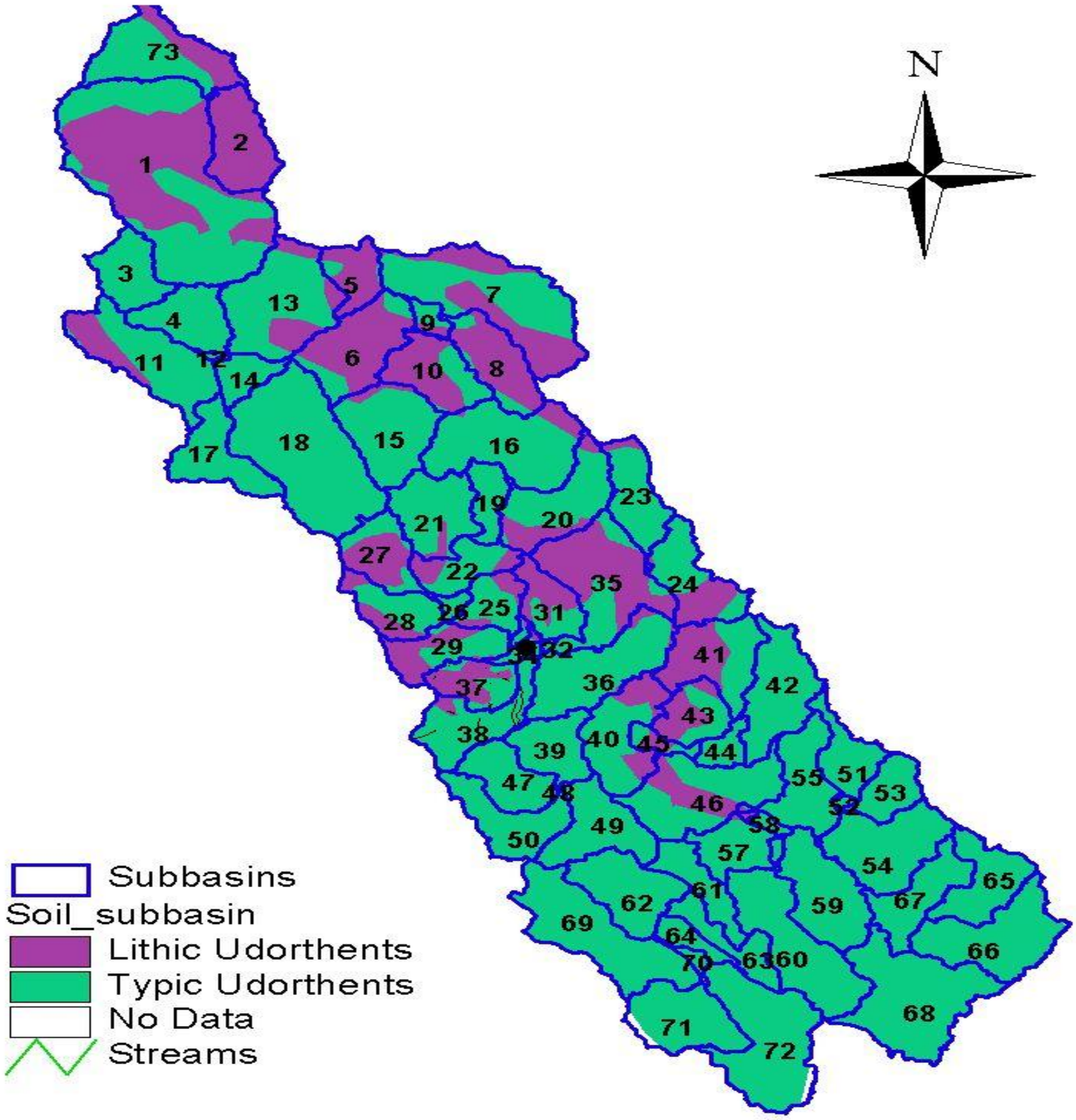

Figure 4: Soil Layer (Source: NBSSLUP)

Table 1 Some soil Units' Description

Soil Type	Area (ha) & % area	Description
Typic Udorthents	1902.599 (59.98)	Medium deep, Well Drained, Moderately steep slopes with loamy surface and severe erosion Associated with Medium deep, Well Drained, Fine-Loamy soils with loamy surface and severe erosion.
Lythic Udorthents	1269.207 (40.02)	Shallow, Excessively Drained, Loamy Soils, Steep slopes with loamy surface and severe erosion, Associated with Medium deep, Well Drained, Fine-Loamy soils with loamy surface and moderate erosion .

2.2.4. Preparation for APEX Model Run

APEX model does not directly utilize GIS to develop input files for the model. However, in the present case watershed delineation application of AVSWAT were used to demarcate subbasins and to generate the topographic variables as required by APEX to build the subarea file, indicating routing mechanism as used for the selected watershed. This step helped in large saving of time as well as automatic generation of the delineated micro watersheds with their inherent drainage network retained. This also provides many elements of data required for model run.

APEX utilizes many of the inputs that are identical to the SWAT model. These include data for soils, climate, topography, and land use. These are model inputs for the study area. Automatic delineation of watersheds is done by using the DEM as input to AVSWAT model. The target outflow point is interactively selected. A threshold value of 25 ha has been used for generating the stream network which primarily decides the density of the stream network and consequently the number of sub basins. Delineated drainage network and sub-basins are shown in Figure 5.

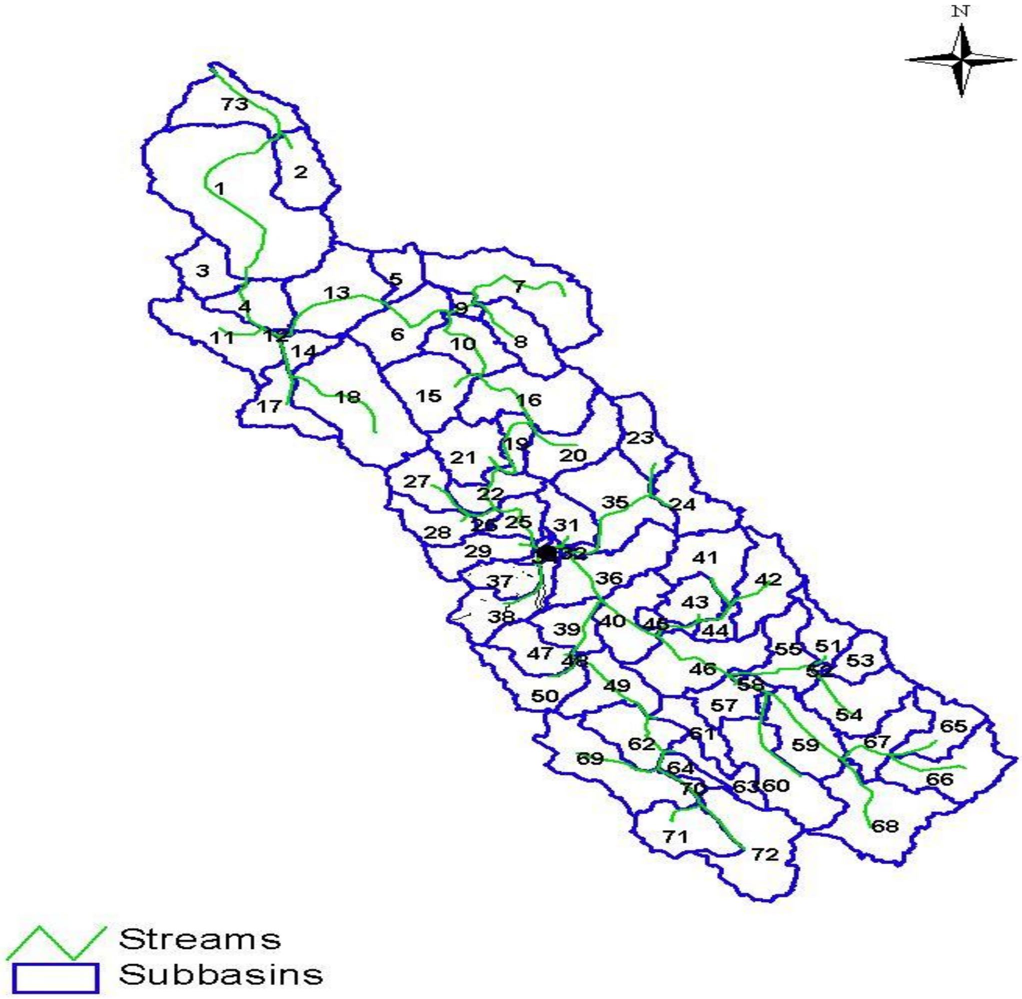

Figure 5: **Salasi Khad watershed with the sub-basins automatically delineated**

III. Results and Discussion:

All input files required to run the APEX model were prepared as discussed using the formatting instructions as given in model program using a DOS. Subarea file were prepared using the flow direction and subarea as shown in figure 5. Topographic variables (such as channel length, slope, slope length, area etc.) required to built subarea file based on flow routing configuration were taken from the watershed delineation application of SWAT. Operation schedule file and other management data in sub area file were entered manually based on the information available for the study area. Daily observed weather data on maximum and minimum temperature, rainfall, relative humidity and wind speed from 1998 to 2002 were used for the simulation. Daily data on solar radiation for the same period were generated from long term weather statistics for nearest location using weather generator given with APEX Model. Model was successfully run using the flow routing configuration as shown in the figure 5. Since the observed flow for this watershed was not available for comparison with simulated flow, therefore simulated daily flow at the final outlet (sub-basin 73) were plotted against the rainfall for some of the years in order to study the behavior of the watershed in terms of variation in flow along with rainfall. Figure 6 provides the daily simulated flows along with the daily rainfall. The variation in annual simulated flow along with observed rainfall for the study period is shown in Table 2.

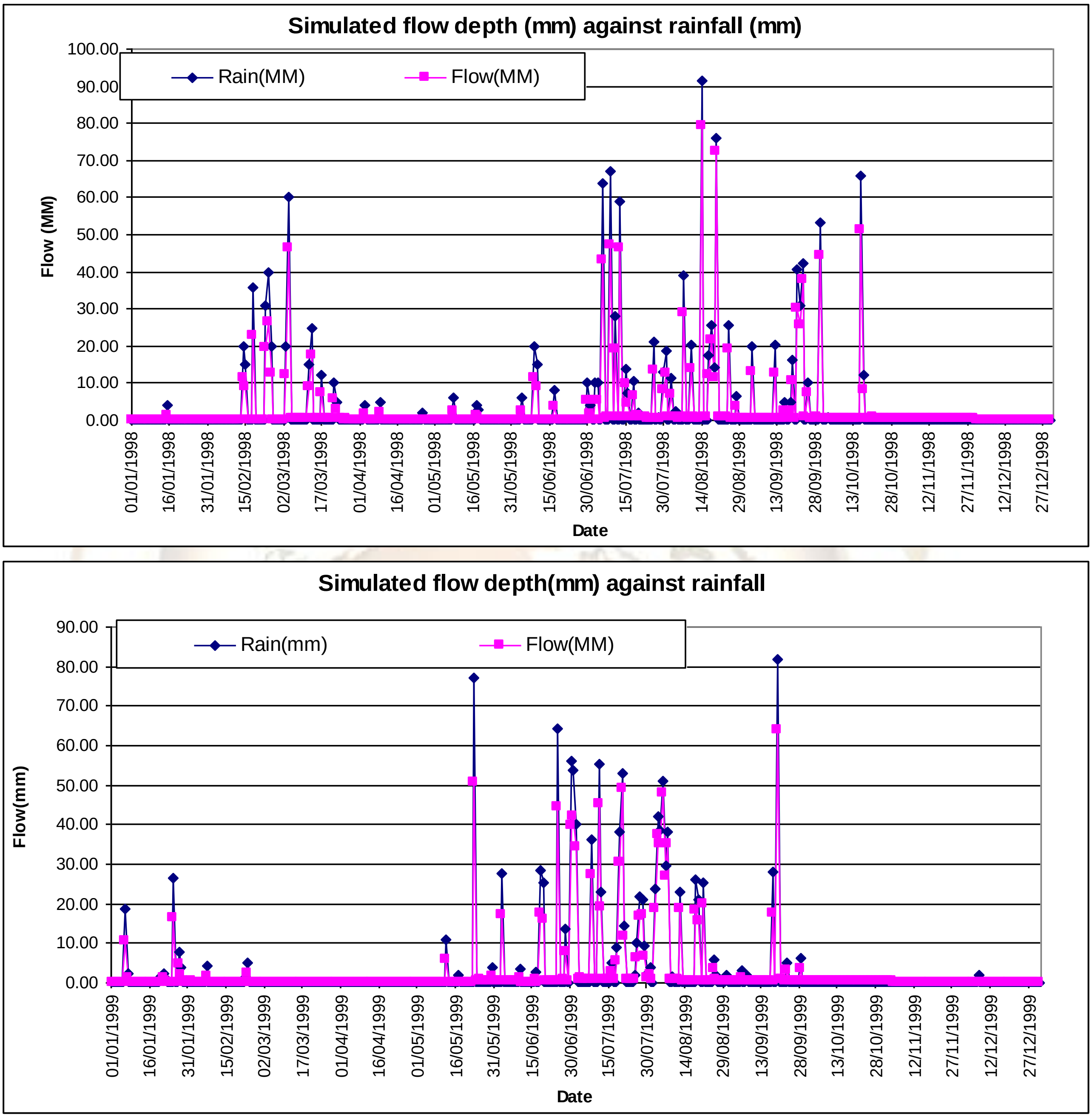

Figure 6: Comparison of Simulated Flow (mm) and rainfall for 1998 (top) and 1999 (bottom)

Table 2: Simulated annual flow depth and observed rainfall in the Salasi watershed

Year	Rainfall (mm)	Simulate flow (mm)
1998	1377.40	1045.87
1999	1246.50	980.07
2000	1515.90	1178.72
2001	1152.95	855.44
2002	932.68	692.67

Though the model could not be tested against the observed flow but the trend in simulated daily flow followed the trend in observed rainfall which indicate that the methodology framework adopted in this study can be used to model the relative changes in flow component under different conservation practices as compared to this base run.

IV. Conclusions

Extensive processing of static and dynamic data for use in APEX model has been performed using GIS technologies. A modeling framework has been prepared to apply APEX model for watershed management in Salasi watershed in Himachal Pradesh India. GIS technologies and watershed delineation application of AVSWAT has been used to generate the required data for APEX Model run. Though the model could not be tested against the observed flow but the trend in simulated daily flow followed the trend in observed rainfall which indicate that the framework can be used to model the relative changes in flow component under different conservation practices as compared to this base run. This APEX Modeling framework may prove to be more appropriate tool for watershed management at field or micro watershed level because of the ability of APEX model to simulate water balance at higher spatial resolution i.e. at field/plot level.

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