Hydrological modeling in hilly watershed with Free and Open Source Software (FOSS)

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***Abstract*—The adversely changing climate, Land Use Land Cover (LULC) and its impact has become global issue in hydrology of mountainous region. A part of dun valley area of Dehradun, i.e., Asan river watershed has seen significant changes in urban landscape in last 15 years. To assess the effect of these changes on hydrological components, an integrated hydrological modeling approach will be needed. Soil and Water Assessment Tool (SWAT) hydrological model has wide spectrum of capabilities to deal with various hydrological, water and land management scenarios. Until 2014, SWAT model required commercial software ArcGIS as GIS interface for running its hydro processing and core water balance modules, whereas, most of the organizations which are involved in hydrology based projects have limited budget. To encourage the expertise and capability of user, open source softwares and tools designed and have similar capability without expenditure. In the present study, QSWAT an open source tool plugin which work with QGIS software, has been used for the estimation of surface runoff and other hydrological variables in the Asan watershed, Dehradun District, Uttarakhand. QGIS-QSWAT has been used for creation of watershed parameters from ASTER GDEM (30m), and different Climatic layers, Soil and LULC are generated as the model input. Continuous daily simulations of hydrological components of Asan watershed was successfully done from 1999 to 2014 using NCEP and ground based climatic data. Calibration and validation was done for year 2007. This preliminary analysis will be taken as a reference for the engineers and planners.**

Keywords- Hilly watershed, open source hydrological model, SWAT, FOSS, QSWAT

I. INTRODUCTION

The purpose of hydrodynamic model is to show the dynamic expansion of a river in multi direction criteria i.e 1D and 2D. Mountainous ecosystem is a bit versatile in hydrological responses due to the water resources of this typical terrain region is naturally irrigated and follows the inconsistent routes. Hydrological modeling of a hilly area is the preferable hydrological management action which involves the management of other hydrological variables. Because the main fetching of the food yielding in hilly area is primary sector, now this is the time to model the hazardous situations due to hydrological cycle those are more applicable to the mountainous area. The vulnerability impacts of hilly region are not only limited to hydrological fluctuations but also due to snow melt runoff, flood sedimentation, flood runoff, water energy, water quality and etc. in the downstream. Running of individual variable in suitable model is quite time consuming process for engineers and analysts by which the action plan is taken as quick response in extreme conditions. But the hydrological variables cannot be measured directly, because of their limitations in measurement and scaling (Beven et al., 2000). In the recent trends, hydrological models have been increasingly used by hydrologists and water resources managers to understand natural and human activities that affect watershed management (Zhang et al., 2008). The hydrological system is unique and it could shows consequences on Land Use Land Cover i.e water quality, sediments and above discussed factors. So many hydro dynamic models are introduced and practiced with the respective variables. An integrated modeling system is difficult to obtain and process with supporting databases and as all commercial software systems are limited of licenses, to overcome this type of challenges, a free available integrated tool will be needed which can calibrate the output hydrological variables. Interdisciplinary modelling has got more advantages, one of them are the Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998) is a continuous, long term, distributed- parameter model that can simulate surface and subsurface flow, soil erosion and sediment deposition, nutrient and their movement through watersheds(Zhang et al., 2008). SWAT model become a good capable of hydrological modelling and water quality analysis along with other artifacts. SWAT has been perform earlier by US Environmental Protection Agency (USEPA) by integrating point and non-point hydrological sources and being applied by the USDA for the Conservation Effect Assessment (CEAP) (Zhang et al., 2008). SWAT can be applied for Daily and monthly stream flow simulations in medium to large watersheds, for example, Zhang et al (2007) have done the simulation for Luohe river watershed, China. SWAT will be applied not only for water quality, hydrological modelling also used for nutrients analysis, pollution management and indirectly responsible for environmental protection and disaster mitigations.

Coming to the new and recent trends of software availability and access, QGIS has been developed from basic level to the advanced set up. The SWAT as a plugin of this toolkit has been called as QSWAT which is freely available and can be downloaded from QSWAT official website directly (http://swat.tamu.edu/software/qswat/). The QSWAT user guide is available in the website recently from May 18th 2015. This friendly GUI (Graphical User Interface) has three steps to reach the final run to generate the variables. Presently the version QSWAT 0.5 and 1.0 is supporting to the QGIS version of 2.6.1-1 with 32 bit version. This is only the small disadvantage of availability of this FOSS (Free and Open Source Software). The three steps of this tool are Delineate the Watershed, Creating HRU's and Edit inputs and run SWAT. The interface of this is similar to the ArcSWAT and a SWAT Editor dialogue box allows to edit the input database and generates the output in required formats. The database files can be edited and updated and the debugging of errors will be easily identified as it is in python scripting.

In the present inventory, the main objectives are, to assess the landuse parameters through free available and Open Source Software (FOSS), exploring the capabilities of the tool and to obtain the various hydrological variables from QSWAT model in Asan river watershed basin.

II. STUDY AREA

Asan watershed is part of Dun valley, Uttarakhand, India, which causes asymmetry of valley and it expanded from NW to SE. The upstream of the river flows in the central part of watershed from SW to NE and the river merges with Yamuna River. The geographic location of Asan watershed is 30° 14' 14"N to 30° 29' 54"N and longitudes 77° 39' 42"E to 78° 05' 30"E and the River is located at 30°21'40.40"N and 78° 1'59.02"E (Kiriwongwattana et al., 2012). The whole basin has

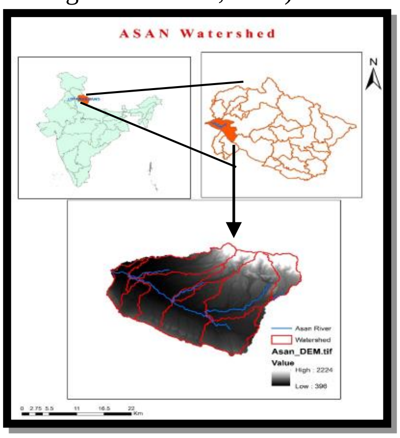

Figure 1. Study Area showing ASAN watershed

the ample of water resources as both of surface and ground. Ground water is the most abundant and main source of both drinking and irrigation. It has different drainage patterns parallel to sub-parallel, sub-dendritic, trellis, angular, rectangular, intermittent and braided. The area of the watershed is approximately 654 Sq.Km (Figure 1).

III. MATERIALS AND METHODS

Simulation of QSWAT requires several inputs as in database. ASTER GDEM (±30m) has been used successfully to obtain the watershed and streamline layers, apart from these layers slope map has been generated successfully. Global LULC and FAO soil data has been used for the generation of HRU (Hydrological Response Units). NCEP (National Center for Environmental Prediction) climatic layers have been used for weather data generation from 1999 to 2014 and the validation has been done for the period of 2007 successfully. Below methodology has been followed to generate the integrated output (Figure 2).

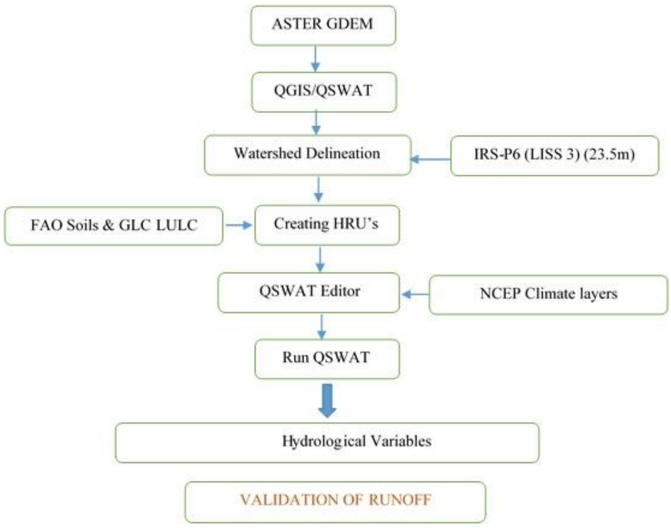

Figure 2. Methodologyc flow chart

A. *Materials*

a) Spatial data

Spatial databases including ASTER DEM, Resourcesat-1 LISS3 image and derived maps such as LULC, Soil, and Climate data of NCEP have been processed (Figure 3).

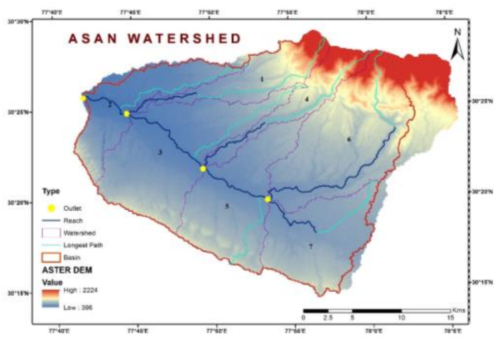

Figure 3. Study Area showing ASAN watershed

b) Weather data generation:

National Centers for Environmental Prediction (NCEP)'s climate data of daily Rainfall (mm) and Temperature (Deg C), Relative Humidity (%), Longwave radiation (Solar radiation) and Wind speed (m/s) has been obtained for input.

B. Methods:

a) Watershed Delineation

This is the one of the most sophisticated and easier method in creating watershed with open source tool. In QSWAT interface, process of delineation involves four steps. Firstly, Watershed Delineation which requires DEM as input create stream line with respect to stream definition. An appropriate output has been generated with 35 Sq.Km area in Asan watershed. Additionally, as discussed in introduction, it takes point (outlet). Second step is to enter existing watershed to make changes of existing watershed and creates new. In the third step, DEM properties will be showed to process the TauDEM output. Fourth step is of processing the TauDEM (Terrain analysis using DEM) output which is a supported output for further hydrological processing. This is an advantage of QSWAT as a free available software. The model divides watersheds into a number of sub-watersheds and adopts the concept of the hydrologic response unit (HRU), which represents the unique property of each parameter such as landuse, soil, and slope (T.Lee et al., 2011). In the present analysis, 7 sub basins have been formed from the given area.

b) Creating HRU's:

Hydrological Response Units (HRU's) has been created for Asan watershed with two inputs are LULC map and Soil information data (Table1). There are two categories in selecting in LULC, out of those global LULC (Global Land Cover - GLC) data has been given as an input and FAO (Food and Agriculture Organization) soil data has been used as usersoil data and global soil table. Asan's watershed slope band information has been defined with 0, 10, 25, 50, 75 and 9999m. Very important step involved in generation of HRU's is to define the percentage threshold which has given output HRU file with consideration 10% of soil, slope and LULC from whole watershed. The output will be seen in a notepad file. It has been observed that the total 99 HRU's have been created form 30 Sq.Km and 10% percentage threshold. The total hydrologic balance has been simulated for each HRU,

TABLE1: MAXIMUM HRU CONTRIBUTION FROM DIFFERENT LULC

Sub Basin	HRUs	Multiple HRUs (LULC/Soil/Slope)	Watershed area (%)	Sub Basin area (%)
1	1	FRSD/Jc/10-25	2.74	30.96
2	10	FRSD/Jc/0-10	3.81	35.79
3	12	FRSD/Jc/0-10	10.02	47.07
4	21	WATR/Jc/0-10	1.79	26.48
5	26	WATR/Jc/0-10	5.12	31.33
6	27	FRSD/Jc/10-25	6.78	30.68
7	33	FRSD/Jc/0-10	8.36	59.71

including all the variables of hydrology, after creating HRU's, such as canopy interception of precipitation, partitioning of precipitation, snowmelt water, runoff and infiliteration and apart from these, redistribution of water within the soil, evapotranspiration, lateral subsurface flow from soil profile and flow from shallow aquifers (P.W Gassman et al 2007), reports will be visualized from select report to view from interface's dropdown button on left side.

c) QSWAT Editor:

QSWAT Editor allowed to enter the climate data i.e Precipitation (mm), Temperature (Deg.C), Relative Humidity (%), Longwave radiation (Solar radiation) and Wind speed (m/s), data also visualized in graphs. This window allowed to modify the inputs, it is the preprocessed step to run the QSWAT.

d) Run QSWAT:

To setup run of QSWAT the starting and end dates have been mentioned from 1979 to 2014, out of the 36 years duration, initial years has been considered as warming up period and model is run for the 16 years. The skewed normal type has been taken as rainfall method, and selected all the required options as output. The 'Daily' rainfall pattern has been selected in printout settings.

e) Integrated Output:

Output of this analysis has been observed that apart from the runoff which is the most required, other hydrological variables have been generated, such as Rainfall, Runoff etc., which will be useful for the analysis of river health in Asan watershed.

IV. RESULTS AND DISCUSSIONS:

A. Hydrological Variables

Asan watershed has been divided into 7 sub basins. Simulation has been done for each sub basin to extract the total average rainfall for the 16 years (1999-2014). NCEP climate layer has been taken as an input for precipitation and temperature from 1999 to 2014.

B. HRUs Table:

From the 34 Multiple HRU's, it has been observed that the dominant percentage of area contributing in each basin to the hydrological response statistics are given below. The total LULC classes are Forest, Urban, Agriculture and Water. The table showing that the maximum watershed area has been covered with the landuse Deciduous Forest with 46318.6 Ha (approximately 76.82%), Water with 16.83% and Agricultural 6.35%. Terrain's slope with more than 15 degree (36.95%), and Maximum soil is covered with Calcaric Fluvisols (FAO-Jc) with almost total area (99.83%) and Dystric cambisols (FAO-Bd) from 602.96 Sq.Km (100%). Final HRU's file showed the result of maximum contribution with above information.

In general runoff of the basin is directly proportional to the rainfall. From the NCEP's average annual rainfall input data, it has been observed that the annual average runoff trend showed well response to that of the rainfall. The total snow melt of the basin has been observed in the month of January.

V. VALIDATION:

Validation of the study has been done with standard literature. Figure 3 showing the runoff trend for the present study. The runoff of the present study has been compared to the runoff trend of published literature which is showing well response and it concluded that the validation has been done successfully. The validation of this study has been done for year 2007(Figure 4).

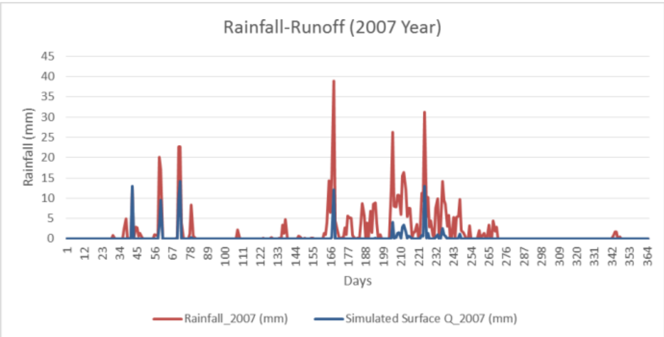

Figure 3. Runoff from total rainfall (present analysis 2007 year)

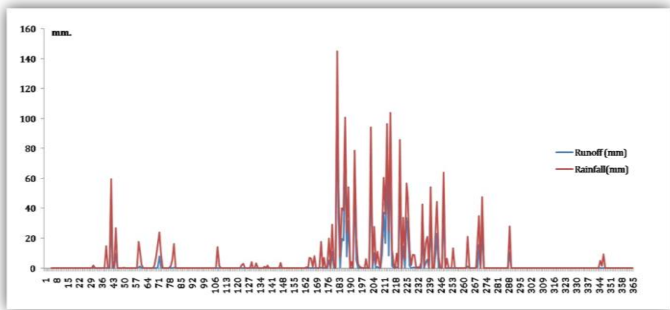

Figure 4. Runoff from total rainfall (2007 year)
(Source: S Kiriwongwattana and S.P.Aggarwal, 2012)

VI. CONCLUSIONS AND RECOMMENDATIONS

Hydrological modeling of Asan watershed hilly region, Uttarakhand has been done with QSWAT. In this analysis, various spatial and non-spatial data have been used for the generation of output. It has been evidently observed that the total average annual runoff of the basin of given area obtained from final output.std file. Validation of the results have been done with standard literature. From the whole analysis, it has been truly observed that the Asan watershed is changing gradually in terms of obtained hydrological parameters from past 16 years. Even though, the rainfall and runoff have been showing the increasing trend information, to be précised, magnitude of the flood peak information will be added to the scope of this study and also the intensive study on water quality will be done. From the whole analysis, it has been clearly observed that QSWAT is more user friendly, being a FOSS it has been contributed to detailed analysis of hydrological variables and it has given a wide scope to interlink this analysis to various fields. This analysis will be more suggested to the decision makers of sustainable development and management.

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