GIS BASED HYDROLOGICAL MODELLING OF EXTREME EVENTS IN A FORESTED MOUNTAINOUS CATCHMENT

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Introduction

Generally in developing economies like India, due to lack of proper infrastructure many watersheds are not been studied hydrologically or only partially gauged. Especially in many mountainous Himalayan watersheds precise data on rainfalls, runoffs are not available. Moreover among these watersheds many are meteorologically prone to severe cloud bursts as well as topographically possess the characteristics of producing flash floods.

Destructions caused by these flash floods are more devastating in terms of loss of human lives, collapse of natural systems and loss of agricultural crops. To achieve the best possible solutions to tackle these problems, scientists should possess first hand information on existing hydrological characteristics in such watersheds before going in for detailed modelling. For this purpose we initiated a research study in an ungauged forested hilly catchment in shiwaliks region of Himalaya. As this research watershed has not been gauged earlier we could not go in for process or physically based modeling approaches. Hence as an alternate solution we have adopted a combination of empirical, conceptual and simplified physically based modeling approach to model few selected extreme events in the small experimental watershed and the results of the same are reported here in this article.

Study watershed description

Catchment area of the Pathri Rao watershed, is situated between the latitude of 29° 06' N to 30° 02' N and longitude of 78° to 78° 06' having an elevation ranging from 290–730 m above mean sea level, MSL (Figure 1). The area is densely forested and form a part of the Rajaji national park area. The geographical area of the catchment is about 25 km^2. The watershed receives an average annual rainfall of 1300 mm with an average of 50 rain days and that more than 90 percent of the annual rainfall occurs during the monsoon season i.e. between June to October. The mean minimum and maximum temperature in the region respectively are 3 ^{0}C and 42 ^{0}C. The mean relative humidity varies from a minimum of 40 percent in April to a maximum of 85 percent in the month of July. The overall climate of the area can be classified as semi arid region. The soil is mainly sandy loam type and the soil depth ranges from 0 to 100 cm. The lower tracts beyond the catchment area have flat slopes and are therefore, densely habituated. An automatic rain gauge station has been installed in the watershed for the purpose of this research study, which records the half hourly rainfall data needed for hydrological studies. Likewise the watershed was gauged during the study period for making comparative study on observed and simulated flood hydrographs.

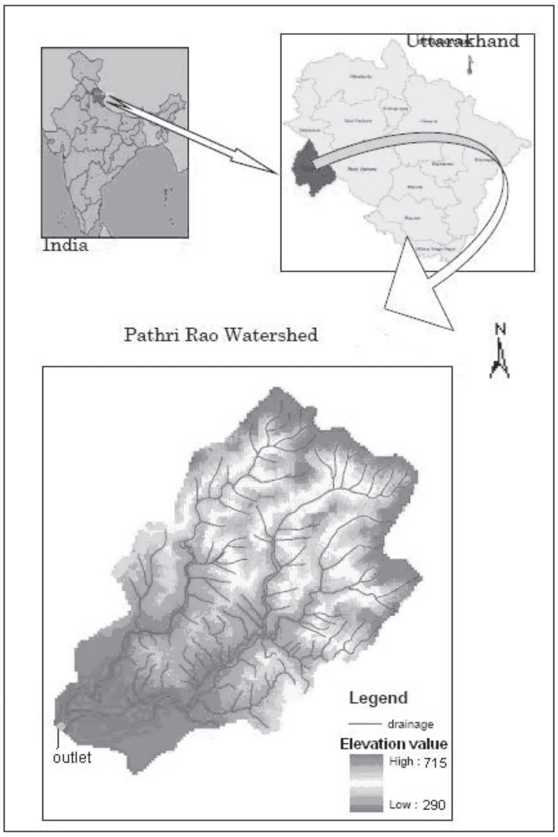

Figure 1. Geographical location of the study area

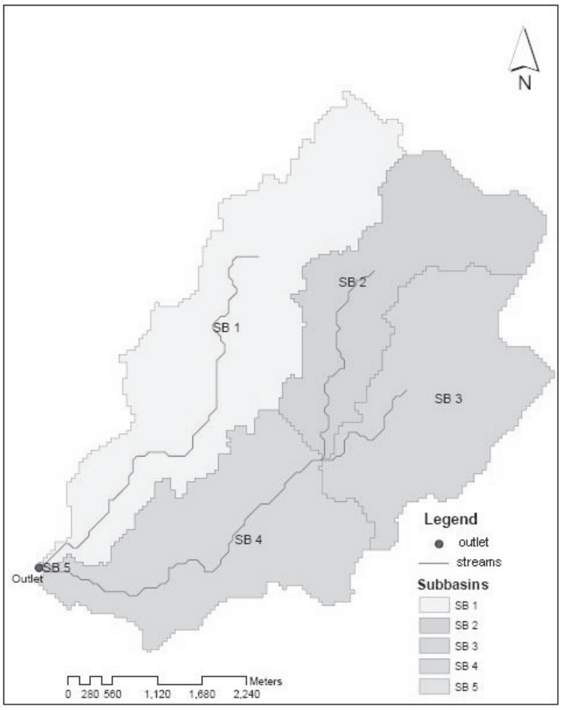

Figure 2. Sub-basin discretization of the study watershed

Materials and methods

Data used:

- Digital Survey of India toposheet (SOI) at a scale of 1: 50,000 having 20 m contour data

- Hydro meteorological data of Pathri Rao watershed for the year 2005.

- Digital soil map of Pathri Rao watershed

- Digital landuse map of the Pathri Rao watershed for the year 2005

Methodology

The hypothesis made in this study is, in a watershed, at the beginning of a rainfall event, part of the rainfall lost as initial loss due to interception of vegetation and then infiltrates into soil till it exceeds the rate at which water can infiltrate the ground (infiltration capacity), and any depression storage has already been filled. Remaining rainfall which is not lost to infiltration is transformed to surface runoff and reaches catchment outlet through streams.

To model the above said catchment processes with limited datasets, we have adopted several geospatial algorithms available in ArcInfo GIS 9.1system on digital elevation model(DEM) of the watershed to derive the sub basins (Figure 2) and its corresponding topographical parameters like slope and longest flow path, channel's length and slope. Then based on the digital analysis of soil texture and landuse maps SCS CN (Soil Conservation Service-Curve number) were derived and averaged for each sub basins. Likewise the channel parameters were obtained through field reconnaissance survey. Details of those derived parameters are reported in tables 1 and 2. Then with meteorological data combined with the above obtained information, few extreme events of monsoon 2005 were modelled as stated in succeeding lines. Here for the selected rainfall events initial loss is assumed to be varying between 10-20% of total rainfall. The Green and Ampt (1911) infiltration approach as described in EM 1110-2-1417 (1994) was then used for computing infiltration losses and the obtained excess rainfall was transformed to each sub basin outlet using SCS transform approach (*NRCS National engineering handbook,* 1972). Subsequently the transformed runoff which enters the channels was hydraulically routed till the catchment outlet using kinematic wave approximations of open surface shallow water equations to obtain the flood hydrograph.

Table 1. Sub basin topographical parameters
SB- sub basin; DDF- Dry Deciduous Forest; SL- Sandy Loam

Element	Area km^2	Major soil type	Major landuse type	Average Curve Number	Average slope degree	Lag (minutes)
SB 1	8.625	SL	DDF	51.86	27.26	42
SB 2	4.89	SL	DDF	54.42	37.40	26.5
SB 3	5.445	SL	DDF	55.34	39.82	21.7
SB 4	5.93	SL	DDF	52.05	12.51	18.4
SB 5	0.505	SL	DDF	82	1.28	13.8

Table 2. Channel routing parameters

Element	Length (m)	Slope	Manning's n	Shape	Bottom width (m)	Side slope (xH: xV)
Channel 1	3752	0.007	0.047	Trapezoid	48	3
Channel 1	56	0.003	0.0043	Trapezoid	57	2.8

Table 3. Meteorological information and calibrated infiltration parameters for all the sub basins
©- Calibration events; (v)-Validation events

Rainfall Event	Rainfall Depth (mm)	Duration (h)	~AMC %	~Initial Loss (mm)	Volumetric moisture content (ratio)	Wetting front head (mm)	Saturated Hydraulic conductivity ($mm \cdot h^{-1}$)
26.6.05 ©	36.07	2.5	0.20 - 0.25	3.7	0.335	45	5.6
23.7.05 (v)	40.34	2.5	0.50 - 0.60	4.1	0.182	45	5.6
4.8.05 (v)	39.04	3.0	0.15 - 0.25	3.95	0.355	45	5.6
6.8.05 ©	24.87	1.5	0.70 - 0.75	3.0	0.151	45	5.6
13.8.05 (v)	11.94	1.0	0.15 - 0.20	1.5	0.382	45	5.6
10.9.05 ©	17.93	1.0	0.25 -0-30	1.8	0.325	45	5.6
18.9.05 (v)	73.49	7.0	0.50 - 0.55	11.75	0.213	45	5.6

Computational process and results

Input data files for all the sub basins were prepared using GIS analysis. The data file of each sub basin contains information about average rainfall, slope, lag time, landuse and soil type. Based on land cover and soil type, a rough estimation of initial loss was quantified. Initial water content was quantified by the likely initial soil saturation degree obtained through analyzing daily rainfall records prior to selected storm events for each sub basins. Then based on the fractions of sand, silt, clay and organic matter for each soil type in each sub basins, the average initial values for other infiltration parameters such as wetting front depth, porosity, saturated hydraulic conductivity values were calculated as per Rawls and Brakensiek (1989). For computation the storm events were divided into two groups. The first group of events, indicated as calibration storms are used for model calibration. The data of other group of events referred to here as verification events were used for the purpose of model validation. Calibration was performed for matching the magnitude of peak, time to peak and volume of observed and computed runoff by systematically altering the value of parameters dependent on soil type, topography and landuse conditions. Table 3 lists the meteorological information and calibrated infiltration parameters for all the rainfall events under study. Then with the calibrated inputs, modeling was done for the storm events selected for the purpose of validation and the corresponding results obtained are shown here in the Table 4 along with the results obtained for calibration events. Finally the model fit was judged as satisfactory by visual matching of observed and computed hydrographs in terms of magnitude of peak, time to peak and volume of the hydrograph.

Table 4. Modeling results for calibrated and validation rainfall events
©- Calibrated events; (v)-Validated events

Rainfall events	Total storm runoff (mm)		Peak runoff rate (m^3/s^{-1})		Time to peak runoff rate (minutes)	
	Observed	Computed	Observed	Computed	Observed	Computed
26.6.05 ©	3.84	2.97	14.37	10.63	195	210
23.7.05 (v)	10.73	8.92	18.07	23.37	175	160
4.8.05 (v)	8.34	4.56	31.09	18.11	125	145
6.8.05 ©	6.41	7.54	37.80	37.39	135	110
13.8.05 (v)	2.56	3.47	13.30	10.33	190	240
10.9.05 ©	2.75	2.55	12.27	10.91	125	140
18.9.05 (v)	17.34	14.41	42.19	34.66	215	245

Summary and conclusions

A combination of empirical, conceptual and simplified physically based distributed modeling approach using GIS is proposed and applied for few extreme rainfall events in a semi arid ungauged forested hilly watershed. The results obtained are within the limits of satisfactory. To conclude, we can ascertain that the information obtained through this approach could serve as a first guess on the existing hydrological characteristics of a watershed, which would be useful for planning watershed management activities. Likewise the requirement of fewer inputs and less complex mathematical formulations makes this proposed modeling approach an efficient way to predict extreme events under the assumed scenarios.

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