SGVU J CLIM CHANGE WATER
Vol. 4, 2017 pp. 28-32
ISSN: 2347-7741

Snowmelt runoff modeling using geospatial techniques-a case study of upper catchment of Indus river upto Leh

Ankita Bhardwaj[1], Abanish Kumar[1] and Pramod Kumar[2]
[1]Jiwaji University, Gwalior, [2]Indian Institute of Remote Sensing, Dehradun.
Corresponding email: ankita.rsgis08@gmail.com

ABSTRACT

Snowmelt is a significant component of the hydrological cycle in the major river systems of North India originating from the Himalaya, namely the Indus, Ganga, Brahamputra and their tributaries. Remote sensing (RS) and Geographic Information Systems (GIS) plays a fundamental role in hydrological applications, because of the synergism between the two techniques; a combined use (Geospatial Technique) should be envisaged by hydrologists. The aim of this paper to show the capabilities of an integration of RS, Image Processing, GIS and database management systems (DBMS) technologies in combination with hydrological models. Indus Basin has been selected for this study and temporal satellite images of year 2000 (WiFs, 188 M) were processed for snow cover recognition. Calibration of the Snowmelt Runoff Model (SRM) for the study area is the main objective of this research that simulates the daily snowmelt runoff. We describe a method for snow mapping using WiFs data and a procedure to estimate retrospectively the accumulated snow water equivalent volume with the SRM. Real time snowmelt forecasts have been generated for study area with the SRM model where snow cover as an input variable. Unsupervised classification method has been applied for snow cover mapping, thematic layers were generated using Aster Digital Elevation Model (DEM) and Arc Hydro customized tool of Arc GIS and map composition of different thematic layers has been carried out by using Arc GIS 9.3. The rainfall and temperature data was extrapolated for different zones of Indus River basin.

Keywords: Snowmelt Runoff Model (SRM); Indus River Basin; Remote Sensing; GIS; Arc Hydro

INTRODUCTION

The Snowmelt–Runoff Model (SRM; also referred as 'Martinec Model' or 'Martinec-Rango model') is designed to simulate and forecast daily stream flow in the mountain basins where snowmelt is a major runoff factor. Most recently, it has also been applied to evaluate the effect of a changed climate on the seasonal snow cover and runoff. SRM was developed by (Martinec, 1975) for small European basins. The snow cover areas of a basin play a very important role in hydrological and climatological behavior. Remotely-sensed observations of snow cover extent provide a useful input for reliable estimates of snowmelt runoff in mountainous watersheds, particularly those with a paucity of ground based data. A number of models predicting seasonal and short-term discharge from snow cover data have been proposed. Snowmelt runoff varies with day-to-day hydro-meteorological conditions. Therefore, models structured for the forecast of snowmelt on a short-term basis become most useful in efficient management and planning of water resources. The snowmelt models for short-term forecasts determine the amount of snow that will be melted by the transfer of energy through radiation, convection, and conduction in a given time period rather than depending on the estimates of the total volume of water held in the snowpack (Hawley et al. 1980). Some complex energy balance models in this category require data on the thermal quality and albedo of snow, solar radiation, cloud cover, and convective heat transfer as input variables for snowmelt forecasts. All such variables are difficult to obtain, but particularly so for remote areas with difficult access.

Space-borne remote sensing methods are playing very important role for snowmelt runoff monitoring and/or forecasting in mountainous basins. Main objective of this study was for deriving the spatially distributed snow covered area (SCA) percentage that is required as one of the main input variables of the hydrological snowmelt runoff model (SRM) from earth observation satellites. SRM requires estimates of SCA on weekly basis (Rango, 1993). Runoff volume induced from snowmelt is directly correlated to the snow covered area. It is therefore of advantage to exploit satellite monitoring instead of modeling the snow coverage from precipitation and temperature (Seidel and Martinec, 2004). At the moment some methods exist for performing the above-mentioned task. But the thing to be done is implementing an operational processing scheme that allows fast, objective and reliable snow cover mapping enabling routine applications of the methods.

SNOW-MELT RUNOFF MODEL

The Martinec-Rango (SRM) model has been successfully used in the United States, Japan, Poland, French Alps and various other parts of the world. In addition to snow cover data, the model requires temperature and precipitation as inputs. These input parameters are necessary in each of the elevation zones. Precipitation and temperature are generally measured in the lower altitudes of the Himalayan basins. These parameters are not representing the higher altitudes of the basin. The degree - day factor is obtained from an empirical formula. The model accepts satellite based snow cover inputs in each of the elevation zones. The model has been modified wherever necessary, to suite the Himalayan watersheds. The snowmelt on any day may be expressed as the ordinate of normal recession curve together with additional discharge due to snowmelt and rain in the catchment on that day, thus the discharge on the n+1th day is given as follows:

Qn+1 = [Csn an (Tn + ΔTn)Sn + Crn Pn] * A * 10000 (1-kn+1) + Qn kn+1 ……(1)
86400

Where,
Q = average daily runoff (m3/s)
C = runoff coefficient expressing the losses as a ratio (runoff/precipitation), with Cs referring to snowmelt and Cr for rainfall.
P = precipitation contributing to runoff (cm). A pre-selected threshold temperature, T critical discriminates precipitation with snowfall
a = degree-day factor (cm oC-1day-1) indicating the snowmelt depth resulting from 1 degree-day
T = number of degree days (oC.day)
ΔT= the adjustment by temperature lapse rate for temperature extrapolation with average hypsometric elevation for various zones
Sn = Ratio of the snow covered area to area of a elevation band
A = area of the basin or zone (km2)
k = recession coefficient indicating the decline of discharge in a period without snowmelt or rainfall
n = sequence of days during the discharge computation period
10000/86400 = conversion from cm km2.d-1 to m3s-1
T, S, P are variables, which need to be determined each day. Cs, Cr, lapse rate to determine T, Tcrit, k are parameters which are characteristic for a given basin or generally, for a given climate

In addition to the above input variables, area-elevation curve of the basin is required. If other basin characteristics are available (forested area, soil conditions, antecedent precipitation, and runoff data), they are useful for determination of model parameters.

MODEL INPUTS
SRM has three main input variables which are temperature, precipitation and snow covered area. These will be mentioned in the following sections. Table 1.1 lists the SRM model variables.

Variable		Symbol	Spatial variability	Mode
Daily Temperature	Max-Min	T	Basin wide-Zonal	S/F
	Average			
Precipitation		P	Basin wide-Zonal	S/F
Snow Covered Area		SCA	Basin wide-Zonal	S/F
*Actual stream flow		Q	Basin wide-Zonal	S/F

Table .1.1 SRM model variables
S: Simulation Mode
F: Forecasting Mode
* Not actually an input variable (used for calculation of model accuracy)

Runoff coefficient (C) = runoff / precipitation
Degree day factor (a): Amount of heat for a 24 hrs with a 1 ºC departure from a reference temperature. Converts number of degree-days into snowmelt depth
Temperature lapse rate (γ): Temperature change with the height
Critical temperature (Tcrit): Determines whether precipitation is snow or rain
Rainfall contributing area (RCA)
Recession coefficient (k): Decline of runoff in a period without precipitation
Time Lag (L): Time elapsed between the center of mass of the effective rainfall/snowmelt and the peak of direct runoff

STUDY AREA
Indus river originating at a height of about 5180m from the Manasarowar in Tibet, River Indus flows northwest through Tibet and enters Jammu and Kashmir. Flowing through the deep valleys of Ladakh, Baltistan and Gilgit, River Indus crosses the Indian border and reaches the plains through Attok in Pakistan. Having a length of about 2880 km, it is one of the longest rivers of the world. Only a length of 709 km of the river is in India. Flowing through the plains of Pakistan, Indus branches out into many distributaries and merges with the Arabian Sea to the south of Karachi. Jhelum, Chenab, Ravi, Beas and Sutlej are the important tributaries of the Indus.
The annual precipitation in the Indus region varies between 5 and 20 inches (125 and 510 mm). Except for the mountainous section of Pakistan, the Indus valley lies in the driest part of the subcontinent.

Northwestern winds sweep the upper Indus valley in winter and bring 4 to 8 inches (100 to 200 mm) of rainfall-vital for the successful growing of wheat and barley. The mountainous region of the upper Indus receives precipitation largely in the form of snow. A large amount of the Indus's water is provided by melting snows and glaciers. The mean daily maximum temperature range is 34-45ºC in summer and 19-20ºC in winter. The mean monthly summer rainfall (July-September) is approximately 75 mm and in winter (December-February) it is less than 5 mm. Ladakh region consists of two districts Leh and Kargil. Leh with an area of 45110 sq. km makes its largest district in the country in terms of area. It is situated between 32º to 36º North Latitude and 75º to 80º East Longitude. The district is bounded by Pakistan occupied Kashmir in the West, China in the north and eastern part, Kargil in the west and Lahul Spiti of Himachal Pradesh in South East. It is at distance of 434 km from Srinagar and 474 km from Manali.

MATERIALS AND METHODS

In the present study, various operations performed for the input data preparation and model execution were executed. The satellite images were downloaded and image rectification operation was performed. Unsupervised classification technique was performed for identification of snow features. ASTER DEM was used for contour generation and preparation of slope map. Invoke ArcHydro was used for delineating watershed boundary and Drainage network was generated. A DEM threshold for elevation map was calculated and elevation map was generated. Thereafter final Snow cover map was prepared and WinSRM Model for estimating snow-melt runoff was evaluated and modeling operation was performed.

DATE	PATH/ ROW (P/R)	SATELLITE DATA
18/09/ 2000	95/47	WIFS (188m Resolution)
02/05/ 2000	96/47	
20/03/2000, 22/06/2000 and 15/11/ 2000	97/47	

Table 1.2: List of satellite data used in the present study

RESULTS AND DISSCUSSIONS

Covered map shows the amounts of snow present on land surface during the day of satellite data acquisition. By using the unsupervised classification, we classified the images into two classes i.e. Snow/ glacier and Others which is shown below in the map (figure 1.2 to 1.6). Figure 1.7 shows the snow cover depletion curve for various elevation bands. It has also been illustrated in Table 1.3.

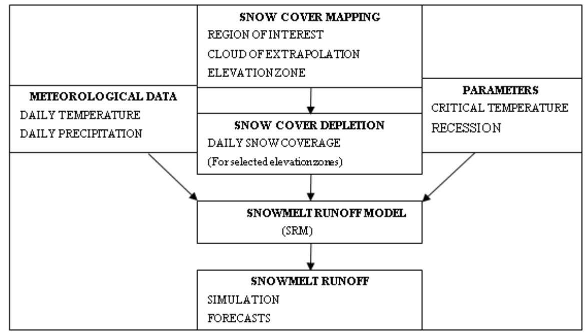

Figure 1: Flowchart of Snow Melt Runoff Model

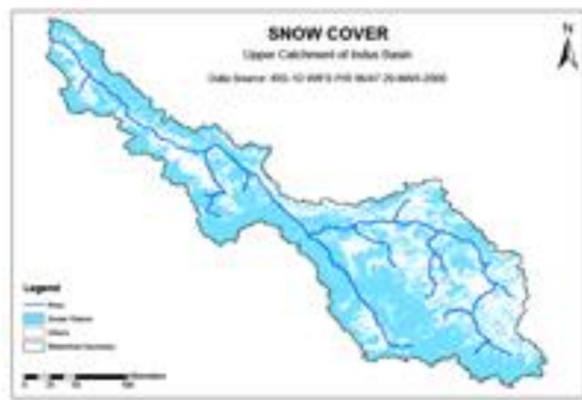

Fig 1.2: Snow cover on 20 Mar, 2000

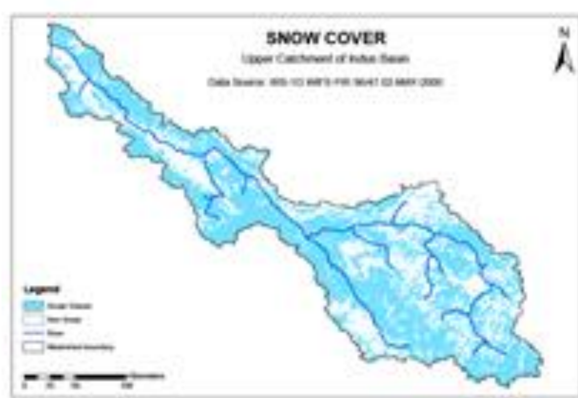

Fig 1.3: Snow cover on 02 May, 2000

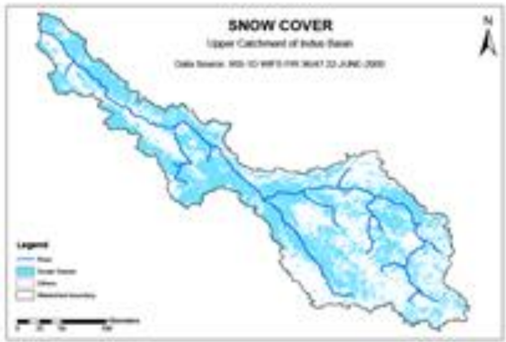

Fig 1.4: Snow cover on 22 Jun, 2000

Fig 1.5: Snow cover on 18 Sep, 2000

Fig 1.6: Snow cover on 15 Nov, 2000

Table 1.4: Elevation Area and mean elevation in different bands.

Sl. No.	Elev_Zone	Mean Elevation	Area (ha)
1	3000-3500	3472.168	29801.86
2	3500-4000	3719.035	55848.7
3	4000-4500	4482.082	519405.9
4	4500-5000	4760.452	1284980
5	5000-5500	5089.288	1326918
6	5500-6000	5551.336	634106.1
7	6000-6500	6030.097	26397.79
8	6500-7000	6541.227	44.11294

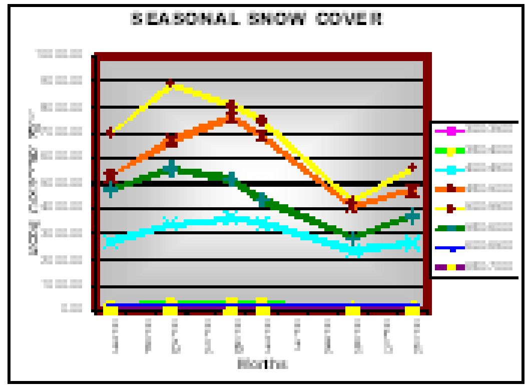

Fig1.7 Seasonal snow covers in various elevation bands.

Table 1.3: Fraction of Snow Cover in different elevation bands.

Image Date	3000-3500	3500-4000	4000-4500	4500-5000	5000-5500	5500-6000	6000-6500	6500-7000	Grand Total
2-May-00	143.72	320.40	3618.64	7570.04	8046.72	5165.46	238.51	0.44	25277.09
15-Nov-00	44.88	137.13	2669.94	4716.37	5624.80	3707.10	179.17	0.44	17201.65
18-Sep-00	40.54	113.16	2381.51	4071.76	4301.94	2865.08	161.15	0.44	14032.44
20-Mar-00	109.17	280.29	3418.20	6704.67	8926.67	5588.02	254.62	0.42	25469.07
22-Jun-00	125.86	313.35	3448.20	6865.39	7480.00	4360.00	203.23	0.44	20137.49

SNOW-MELT RUNOFF

Following the program execution, the snowmelt runoff has been estimated for the upper catchment of Indus river. The runoff volume for melt season has been estimated as 1398.6 MCM against the measured runoff volume of 1376.2 MCM. The average computed runoff has been obtained as 51.88 cumec against the average measured runoff of 51.06 cumec. Thus, the volume difference has been obtained as -1.6% which has been observed to be satisfactory. However, the coefficient of determination has been observed to be relatively low i.e., 0.42. This leads to conclusion that further input refinements are necessary in order to adequately estimate the runoff values emanating from Indus river.

Sl. No.	NE	SE	SW	NW
1	34.24	17.33	30.60	17.83
2	23.47	24.14	28.23	24.15
3	27.33	22.92	27.73	22.02
4	26.77	23.30	26.28	23.65
5	27.47	24.44	24.01	24.07
6	26.38	26.57	23.28	23.77
7	23.17	29.69	22.10	25.05
8	54.26	30.49	8.79	6.46

Table 1.5: Percentage Area in various Aspect Zones.

CONCLUSIONS

Present study has been carried out in upper catchment of Indus river upto Leh in order to estimate the runoff volumes and discharge emanating due to snowmelt. WinSRM model has been used to estimate the snowmelt from the catchment. Various input parameters namely, snow cover, mean elevation and elevation bands, aspect, temperature, degree-day factor, runoff coefficients, temperature lapse rate have been computed and used for snow melt runoff computation. Following conclusions have been drawn from the study. The runoff volume for melt season has been estimated as 1398.6 MCM against the measured runoff volume of 1376.2 MCM. The average computed runoff has been obtained as 51.88 cumec against the average measured runoff of 51.06 cumec. Thus, the volume difference has been obtained as -1.6% which has been observed to be satisfactory. However, the coefficient of determination has been observed to be relatively low i.e., 0.42. This leads to conclusion that further input refinements are necessary in order to adequately estimate the runoff values emanating from Indus river.

The SRM model is a suitable tool to calculate runoff from snow using meteorological data and remote sensing derived snow cover maps. In mountainous areas, the satellite images have great potential to determine and map the snow cover. Monitoring of snow covered area with satellite images, as quantitative data, improves the standard methods and hydrological tools by using spatial analysis. Satellite data accompanied with GIS method can be used to define the snow line and snow depletion curve for different elevation zones. Graphical display of simulation results proved the reliability of the SRM model in snowmelt runoff determination. Temperature is the most important variable in snowmelt that some of the model parameters (degree-day) are related to it.

REFERENCES

Michael F. Baumgartner and G. Apfl, 1993, Integrated Geographic Analysis System with Remote Sensing, GIS and Consecutive Modeling for Snow cover Monitoring, *International Journal of Remote Sensing*, Volume 15, Issue 7, Pages 1507-1517.

Hawley M. E., McCuen, R. H. and Rango A., 1980, *Comparison of Models for Forecasting Snowmelt Runoff Volumes, Journal of the American Water Resources Association*, Paper No. 80061 of the Water Resources Bulletin.

Martinec J., 1975, Snowmelt-Runoff Model for Stream Flow Forecasts, *Journal of Hydrology* Research, Volume 6, Issue 3, Pages 145-154.

Martinec, J. and Rango A., 1996, *The Degree-Day Factor for Snowmelt-Runoff Forecasting, Journal of the American Water Resources Association,* Paper No. 94164 of the Water Resources Bulletin.

Martinec, J. and Rango A., 1986, Parameter Values for Snowmelt Runoff Modeling, *Journal of Hydrology Research,* Volume 84, Issue 1-4, Pages 197-219.

Rango A. and Martinec, J., 1981, Accuracy of Snowmelt Simulation, *Journal of Hydrology* Research, Volume 12, Issue 4-5, Pages 265-274.

Rango A. and Roberts R., 1998, *Snowmelt Runoff Model (SRM) User's Manual, Journal of Water Science and Engineering,* Volume 5, Issue 2, Pages 123-136.

Rango A. and Itten K. I., 1989, Satellite Potentials in Snow cover Monitoring and Runoff Prediction, *Journal of Remote Sensing & Environment,* Volume 28, Pages 09-22.

Rango A., Salomonson V. V. and Foster J. L., 1977, Seasonal Stream flow Estimation in the Himalayan Region Employing Meteorological Satellite Snow cover Observations, *International Journal of Water & Energy, Volume* 58, Issue 1, Pages 65-72.