Snowmelt Runoff Estimation of Jhelum Basin with SRM Model

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***Abstract*—Precipitation is a form of crystalline water ice is called snow. In many parts of the world acts as a natural reservoir that plays an important role for water supply. Snow is a great water reservoir, but when it melts it causes flooding. To prevent the losses from flooding snowmelt modeling is needed. Snowmelt modeling helps in estimating the water discharge for whole year therefore snowmelt can play a vital role in controlling the flood problems along with the water resources management.**

Snowmelt modeling can be done from field observations or satellite observations. Melt water from field observations has been difficult to estimate due to lack of direct measurements and physical input required for model simulation, so that satellite data was preferred for snowmelt modeling. In present study SRM (snowmelt runoff model) model was used for estimation of the runoff of Jhelum basin, India. SRM was used for runoff estimation because SRM model is primarily based on snow cover extent and work on degree-day approach method.

Five major tributaries in India are Satluj, Beas, Ravi Chenab and Jhelum out of these five Jhelum Basin was selected for the study. Repetitive satellite images of hydrological year 2006-2007 of sensor AWiFS and MODIS were processed to determine snow cover.

The main form of precipitation is snow in the basin; hence SRM model was used to estimate the runoff for the period 2006 by using the metrological and satellite data of 2006. Measured runoff was compared with the computed runoff of SRM Model.

Keywords—Jhelum basin, digital elevation model, snow covered area, SRM model, runoff simulation

I. INTRODUCTION

A. General

The term precipitation denotes all forms of water that reaches to earth surface from the atmosphere. The usual forms of rainfall, snowfall, hail, frost and dew. From of all these, only rainfall and snowfall contribute significant amount of water. Rainfall is the principal form of precipitation in India and snow is another important form of precipitation. Snow consists if ice crystals which usually combine to form flakes. [1]

B. importance of snow

Snow is an important part of hydrologic cycle and considered as a dominant source of stream flow in many parts of the world. The geographical distribution of snow indicates a general increase in both snowfall and snow cover with an increase in latitude and altitude. Accurate estimates of the volume of water stored in the basin in the form of snow in winter and its rate of release due to melting in summer are needed for many purposes, including stream flow and flood forecasting, reservoir operation, watershed management, water supply, and design of hydraulic structures. The planning of new multipurpose projects further emphasizes the need for reliable estimates from rain, snow, and glacier runoff. [2]

Nature has blessed India with the Icy peaks of the Himalayas in North of the country. Large areas in the Himalayas are also covered by snow during winters. Area of snow can change significantly during winter and spring. This can affect stream flow for rivers originating in the higher Himalayas. All the river originating from Himalayas receive almost 30-50% of annual flow from snow and glaciers melt run off. In addition, snow pack ablation is highly sensitive to climatic variation. Increase in atmospheric temperature can influence snow melt and stream runoff pattern [3]

C. Conventional methods for estimating Runoff

Several simulation models accounting for snow accumulation and melting processes have been developed worldwide. Hydrological simulation models that include snow are generally divided into three components namely snow cover, precipitation- runoff relationship and runoff distribution and routing procedures.

- Snowmelt Model (SNOWMOD)
- Sreamflow Synthesis and Reservoir Regulation (SSARR)
- Snowmelt Runoff Model (SRM)
- University of British Columbia Watershed Model (UBC)
- Hydrological Engineering Centre (HEC-1) Model
- National Weather Service Snow Accumulation and Ablation Model
- HBV model [2]

D. Remote sensing in snow cover monitoring

Remote sensing techniques are the only way to analyze glaciers in remote mountains and they are certainly the only way to monitor a large number of glaciers simultaneously.[4]

Snowmelt Runoff Model (SRM) is one of a very few models in the world today that requires remote sensing derived snow cover as model input. Owing to its simple data requirements and use of remote sensing to provide snow cover information, SRM is ideal for use in data sparse regions, particularly in remote and inaccessible high mountain watersheds. [5]

E. Types of models for snowmelt runoff

- Energy budget approach
- Degree-day approach

Energy budget approach:

This method involves accounting of the incoming energy, outgoing energy and the change in energy storage for a snow pack for a given time period. The net energy is then expressed as equivalent of snowmelt. The energy balance of the snow pack for any time interval can be expressed as;

$$Q_m = Q_{nr} + Q_h + Q_e + Q_p + Q_g + Q_q \quad (1)$$

Where,

Q_m = Energy available for melting of snowpack
Q_{nr} = Net radiation
Q_h = Sensible or convective heat from the air
Q_e = Latent heat evaporation, condensation or sublimation
Q_p = Heat content of rainwater
Q_g = Heat gained through conduction from underground
Q_q = Change of internal energy of the snowpack

The positive value of Q_m will result in the melting of snow. [6]

Degree-day approach:

In the Himalayan Mountains, the meteorological network for data collection is very poor. The most generally available data are daily maximum and minimum temperatures, humidity measurements and surface wind speed. Temperature indices are widely used in the snowmelt estimation because it is generally considered to be the best index of the heat transfer processes associated with snowmelt. Air temperature expressed in Degree-Day is used in snowmelt computations as an index of the complex energy balance leading to snowmelt. A degree-day is a unit expressing the amount of heat in terms of persistence of a temperature for 24-hour period of one degree centigrade departure from a reference temperature.[6]

The degree-day factor *a* [cm/C°d] converts the number of degree-days T [C°·d] into the daily snowmelt depth M [cm]:

$$M = a \cdot T \quad (2)$$

In the absence of detailed data, the degree-day factor can be obtained from an empirical relation:

$$a = 1.1 \quad (3)$$

Where,
a= degree day factor
ρ_s= density of snow
ρ_w= density of water

When the snow density increases, the albedo decreases and the liquid water content in snow increases, thus the snow density is an index of the changing properties which favour the snowmelt. [7]
Out of Energy budget approach and degree-day approach, degree day approach was adopted for the study. The most thorough method for the estimation of runoff is energy balance method but this method is data intensive and due to lack to data degree-day method was adopted for study. [8]

F. SRM Model

The Snowmelt-Runoff Model (SRM) is designed to simulate and forecast daily stream flow in mountain basins where snowmelt is a major runoff factor. SRM was developed by Martinec (1975) in small European basins. SRM can be applied in mountain basins of almost any size (so far from 0.76 to 917,444 km^2) and any elevation range. A model run starts with a known or estimated discharge value and can proceed for an unlimited number of days, as long as the input variables - temperature, precipitation and snow covered area - are provided. [7]

MODEL STRUCTURE

Each day, the water produced from snowmelt and from rainfall is computed, superimposed on the calculated recession flow and transformed into daily discharge from the basin according to Equation:

$$Q_{n+1} = [\, c_{sn}.a_n (T_n+\Delta T_n) S_n + C_{Rn}P_n] (A.10000/86400) (1 K_{n+1}) + Q_n K_{n+1} \quad (4)$$

Where:

Q = average daily discharge [m^3/s]
C = runoff coefficient expressing the losses as a ratio (runoff/precipitation), with C_s referring to snowmelt and C_r to rain
a = degree-day factor [cm/C°d] indicating the snowmelt depth resulting from 1 degree-day
T = number of degree-days [C° d]
ΔT = the adjustment by temperature lapse rate when extrapolating the temperature from the station to the average hypsometric elevation of the basin or zone [C° d]
S = ratio of the snow covered area to the total area
P = precipitation contributing to runoff [cm]. A preselected threshold temperature, TCRIT, determines whether this contribution is rainfall and immediate. If precipitation is determined by TCRIT to be new snow, it is kept on storage over the hitherto snow free area until melting conditions occur. A = area of the basin or zone [km^2]
k = recession coefficient indicating the decline of discharge in a period without snowmelt or rainfall:
k = Q_m (m, m + 1 are the sequence of days during a true recession flow period).

Conversion from cm.km²/d tom³/s = 10000/86400

T, S and P are variables to be measured or determined each day, C_r, C_s, lapse rate to determine ΔT, TCRIT, and the lag time are parameters which are characteristic for a given basin or, more generally, for a given climate. If the elevation range of the basin exceeds 500 m, it is recommended that the basin be subdivided into elevation zones of about 500m each. For elevation range of 1500m and three elevation zones A, B and C.

The indices A, B and C refer to the respective elevation zones and a time lag of 24 hours is assumed. Other time lags can be selected and automatically taken into account as explained above.

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In the simulation model, SRM can function without updating. The discharge data serve only to evaluate the accuracy of simulation. In ungauged basins the simulation is started with a discharge estimated by analogy to a nearly gauged basin. In the forecasting mode, the model provided an option for updating by the actual discharge every 1-9 days.

Recently, the runoff was modelled in the basin of the Ganges River, which has an area of 917,444 km2 and an elevation range from 0 to 8,840 m a.s.l. Contrary to the original assumptions, there appear to be no limits for application with regard to the basin size and the elevation range. [3]

II. LITERATURE REVIEW:

Snowmelt is the runoff that results from melting snow. Runoff is the component of precipitation that moves across the land surface or through surface channels. Snow is a significant component of the hydrological cycle especially in watersheds of high latitude or higher altitudes. The processes that are responsible for the timing and quantity of snowfall are reasonably well understood. However, melt water from snow as runoff has been difficult to model due to lack of direct measurements and physical input required for model simulation. Snow fall has considerable effect on landscape changes, global climate, and the hydrological cycle.[9]

Snowmelt models are used to estimate runoff. There are two different types of models: Degree-day model or Temperature index model relating melt solely to air temperature and treating the snowpack as a single layer, and energy balance models considering different snow layers and having routines for the water transport through the snowpack. The commonly used degree-day method performs well for homogeneous river basins. While energy balance computations at point scale are successful, the transfer of energy balance models from the point scale to basin scale has not been very successful. The degree-day method is better able to model average conditions. It is, however, not possible to use a degree-day method, to compute melt over short periods only.[10]. So degree-day method was adopted for the runoff estimation due to lack of layered data of snow cover.

There are two main reasons why SRM was selected for this study:

1. The strength of SRM is its primary reliance on snow cover extent. This allows for limited data input needs, and the snow- covered- area can be derived from satellite, aircraft, or ground measurements.
2. Secondly the (WMO 1986) study of intercomparison of various models proves SRM the best of all.[11]

The SRM is a Degree-Day based model to simulate snowmelt runoff. It can simulate daily discharge hydrograph. The model accuracy in high flow condition reduces sensibly, but has good agreement in normal condition. Generally, model outputs are in good agreement with measured data. This model can be used to estimate daily discharge to water management project in mountain basins.[12]

The snowmelt runoff for the hydrological year of (2001) on Pahalgam Valley was simulated using SRM model. The obtained results show that, the SRM model is best tool for computing the snowmelt runoff in the mountainous areas and it is recommended for other catchments. SRM model is very sensitive to input data especially temperature and located in very low altitude range, it is recommended that the catchment should be equipped with temperature monitoring and rain gauge stations at as high altitudes as possible.[13]

Snow cover is an important variable for the climate and hydrological model due to its effect on energy and moisture budgets. Mountains have a strong impact on spatial distribution of precipitation. The knowledge of distribution of snow is critical in planning and management of water resources, runoff simulation. [14]

Snow covered area was taken for the study not volume because Snow covered area is the input variable for SRM model.

III. STUDY AREA

The Jhelum (Vyeth in Kashmiri, Vetesta in Sanskrit and Hydaspes in Greek) is the main waterway of the Kashmir valley. The river Jhelum is a major tributary of the Indus basin. Jhelum River originates from a magnificent spring called “Chashma Verinag”.[15]

The Jhelum basin is located in northern India. The river Jhelum rises from Verinag Spring situated at the foot of the Pir Panjal in the south-eastern part of the valley of Kashmir in India and receives tributaries from the southern slopes of the Greater Himalaya which are fed in part by glaciers and partly by the melting of seasonal snow. It drains alluvial lands in the Kashmir Valley and flows through the large Wular Lake which significantly attenuates the seasonal flood wave. [16]

The total geographical area of Jhelum basin up to Indo-Pakistan border is about 34775 km^2. With a total length of 402 Kms. But the length of Jhelum in India up to existing ceasefire line is about 165 Kms. With a catchment area of about 17622 Sq. Kms. and lies 32°-58'-42" to 35°-08'-02" north latitude and 73°-23'-32" to 75°-35'-57" east longitude and is mainly confined within the Kashmir Valley in India, And a portion of it is chosen for study which is located between 34°23´N to 33°45´N and 74°24´E to 75°10´E. This catchment belongs to the Jhelum river basin. The whole study area is approximately 1649.34 km^2 upto the discharge measuring station Gulmarg.

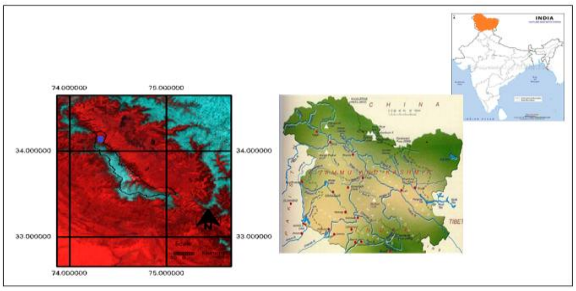

Fig 1. Location of Jhelum Basin

IV. REMOTE SENSING DATA PROCESSING

Remote sensing plays very important role in snowmelt runoff modelling. The present study deals with the estimation of snow cover area and estimation of snowmelt runoff in Jhelum Basin India. In the present study, ERDAS imagine 9.1 have been used for creation of data base required for simulation of Runoff model. Due to the data constraints Snowmelt Runoff

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Model (SRM) was used to estimate the snow melt runoff in Jhelum basin during, year 2006.

Three input of the model are:

1. The characteristics of the basin with inputs area of each zone and hypsometric mean elevation of that zone, which is to be obtained from area elevation curve of the study area.
2. The snow cover, rainfall, and temperature data as input variables.
3. The parameters for the basin, which are; runoff coefficient for snow, critical temperature, runoff coefficient for rain, rainfall contributing area, degree day factor, recession coefficient, temperature lapse rate and time lag. These parameters are used to calibrate the model

The satellite data is required for the computation the model variables and parameters.

A. Basin Area extraction

For extraction of the study area image was processed in ERDAS Imagine 9.1. Study area was extracted from image by superimposition of the vector layer on the image.

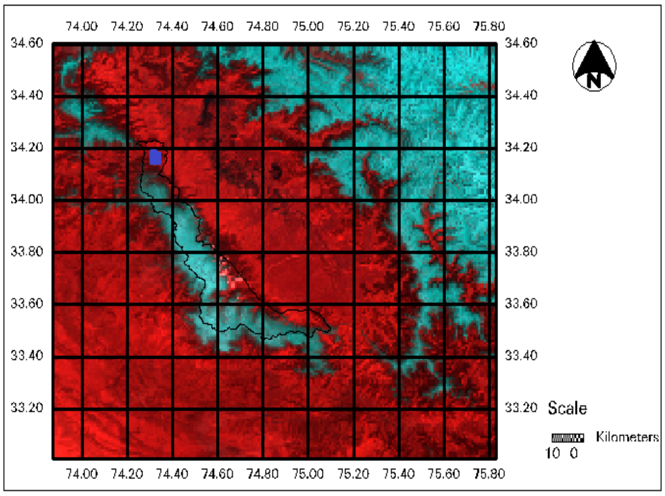

Fig 2. Extraction of study area

B. Digital Elevation Model

Headings Digital elevation model (DEM) is one of the fundamental tools in remote sensing analysis and image processing. DEMs of the study area were downloaded from (http://gdem.ersdac.jspacesystems.or.jp/).
A set of 4 DEMs was downloaded from ASTER DEM site and then those DEMs were processed in ERDAS Imagine for extracting the study area DEM. Mosaic is a command in ERDAS Imagine 9.1 for joining two or more images. First Mosaic is operated to make the full DEM view for the study area and then with the help of raster tools Jhelum basin area was extracted out.

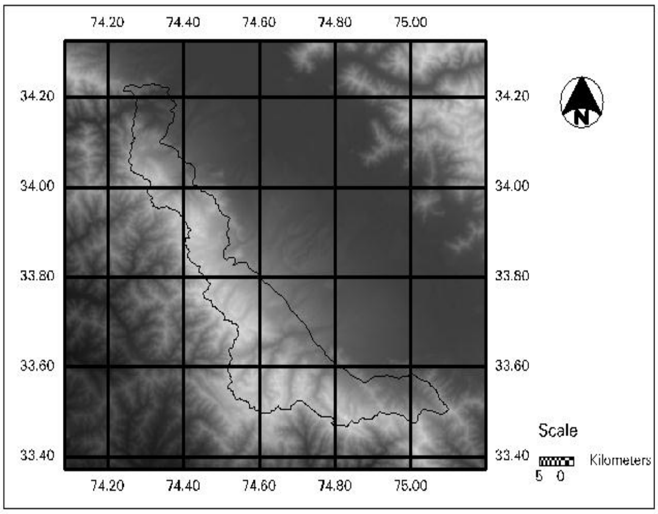

Fig 3. Extracted DEM of the Jhelum basin area

C. zonation

For the modelling of snowmelt runoff, the catchment had to be subdivided into elevation zones. For creating the zone map for the study area the DEM of the Jhelum Basin was used. The area was divided into 7 Zones. The boundary altitudes between the zones were defined based on an elevation/area curve.

In the present study elevation range was from 1534-4714 m and this elevation range was divided into 7 sub divisions which are called zones.

Study area i.e. Jhelum Basin in divided into 7 elevation zones in ERDAS imagine 9.1 with the help of modular. Model was made which divides the whole area with the elevation gap of 400 m and area under these 7 zones was calculated. Which was used to calculate the basin area and snow cover extent to the total area of that zone.

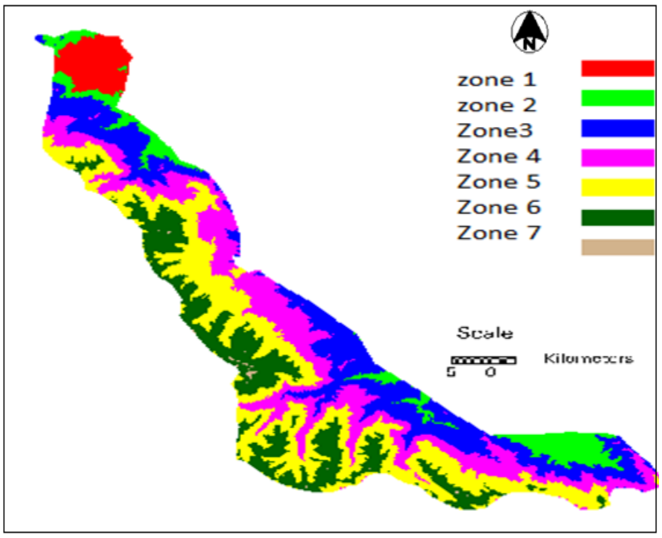

Fig 4. Representation of Zoning of the Jhelum basin into 7 zones

D. Snow covered area

a) Snow monitoring from satellite images

Even It is a typical feature of mountain basins that the areal extent of the seasonal snow cover gradually decreases during the snowmelt season. Depletion curves of the snow coverage can be interpolated from periodical snow cover mapping so that the daily values can be read off as an important input variable to SRM. The snow cover can be mapped by terrestrial observations (in very small basins), by aircraft photography (especially in a flood emergency) and, most efficiently, by satellites. The minimum area which can be mapped with an adequate accuracy depends on the spatial resolution of the remote sensor.

For the snow cover extraction in the Jhelum basin AWIFS and MODIS satellite images were used. The images were available for the period from March 2006 to May 2006.

Snow covered area was computed in ERDAS imagine 9.1.A model is made with modular in ERDAS imagine 9.1, to differentiate snow and clouds visible and near infrared band of MODIS image were taken for processing in ERDAS and NDSI was calculated for all the images of MODIS and for Awifs images Green and SWIR were taken to calculate NDSI.

The NDSI is a normalized ratio of the difference in reflectance in these bands that takes advantage of the unique signature and spectral differences to identify snow from surrounding features even clouds. The equation for the NDSI is

NDSI= (Green Band – SWIR Band or IR Band)/(Green Band + SWIR Band or IR Band)

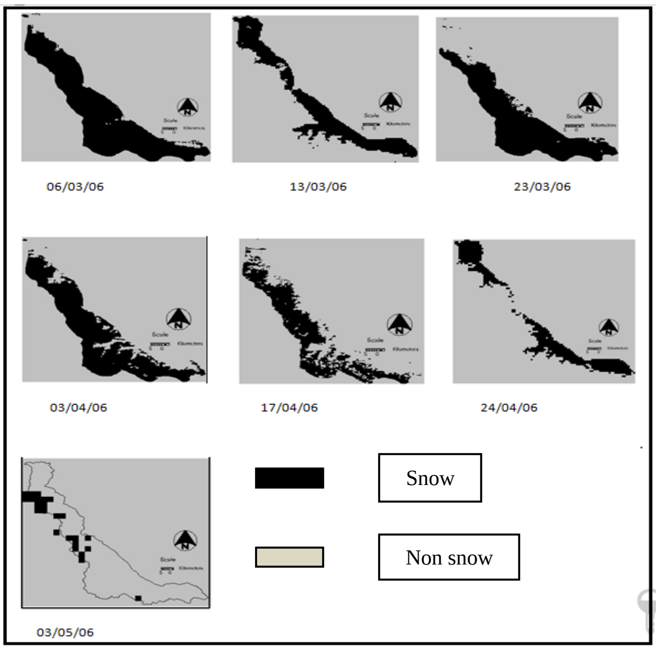

Fig 5. Snow covered area in the basin on different-different dates

Table 1. Snow covered area and % of snow cover

Date	Snow covered Area (Km^2)	Snow cover %
06-03-06	1486.75	90.14%
13-03-06	857.37	51.98%
23-03-06	1329.09	80.53%
03-04-06	1307.72	79%
17-04-06	907.09	54.99%
24-04-06	586.04	35.53%
03-05-06	170.92	10.36%
30-05-06	0	0%

V. RUNOFF ESTIMATION WITH SRM MODEL

A. Input data for running the model

- Basin characteristics
- Variables
- Parameters

1) Basin characteristicsand:

Area elevation curve

By using the zone boundaries plus other selected contour lines in the basin, the areas enclosed by various elevation contours is determined in ERDAS. These data are plotted (area Vs elevation) and an area-elevation (hypsometric) curve derived as shown in Figure for the Jhelum basin. The zone mean hypsometric elevation, h, is then determined from this curve by balancing the areas above and below the mean elevation as shown in Figure. The h value is used as the elevation to which base station temperatures are extrapolated for the calculation of zone degree-days.

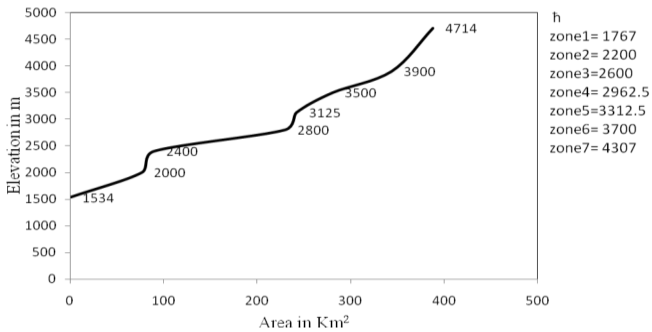

Fig 6. Area-Elevation curve of the Jhelum basin

2) Variables

- Temperature
- Precipitation
- Snow covered area

These variables basically describe the actual metrological conditions for the simulated periods. These data have to be obtained preferably from in situ measurement, but the snow cover is defined by remote sensing.

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a) Temperature

Table 2. Representation of ΔT values zone wise

Zones	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
ΔT	5.99	3.18	.58	0	0	0	0

b) Precipitation

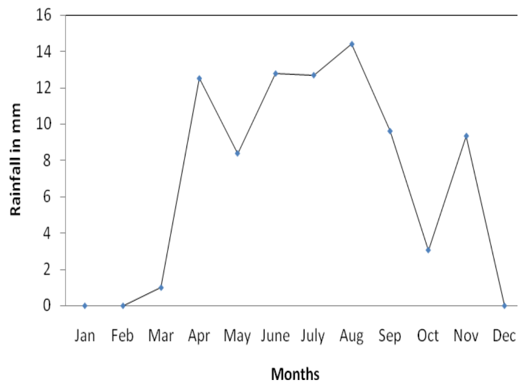

Fig 7. Representation of precipitation plot for 2006

c) Snow covered area

Table 3. CDC values calculation from snow covered area of the study area

Date	Snow covered area (Km^2)	Snow cover %	CDC
06-03-06	1486.75	90.14%	0.9014
13-03-06	857.37	51.98%	0.5198
23-03-06	1329.09	80.53%	0.8058
03-04-06	1307.72	79%	0.7928
17-04-06	907.09	54.99%	0.5499
24-04-06	586.04	35.53%	0.3553
03-05-06	170.92	10.36%	0.1036
30-05-06	0	0%	0

3) Parameters of SRM Model

- RUNOFF COEFF. SNOW
- CRITICAL TEMPERATURE
- RUNOFF COEFF. RAIN
- RAINFALL CONTRIBUTING AREA
- DEGREE DAY FACTOR
- RECESSION COEFF.
- TEMPERATURE LAPSE RATE
- TIME LAG

a) Runoff coefficient, c

This coefficient takes care of the losses, which are to say of the difference between the available water volume (snowmelt + rainfall) and the outflow from the basin.

As there were no snow fall in June, July, August, September and 0 Snow depth were recorded so in that case all the runoff was due to rainfall. So for calculation of Runoff coefficient of rain:

$$C_R = 0.367$$

As there were no rainfall in Jan so all the discharge available was due to snow melt. So for the calculation of runoff coefficient of snow:

$$C_s = 0.47$$

b) Degree-day factor, a

The degree-day factor *a* [cm/ C°d] converts the number of degree-days T [C°·d] into the daily snowmelt depth M [cm]:

$$M = a \cdot T \qquad (5)$$

The range of degree-day values changes between 0.22-1.32 based on the hydrological condition of the basins. For maximum runoff content is 1.32, minimum runoff content is 0.1, and the mean condition for the basin is 0.62-0.96.

c) Temperature lapse rate, γ

If temperature stations at different altitude are available, the lapse rate can be predetermined from historical data. Due to lack of temperature data of the every station .this caused the inaccurate results in lapse rate. Based on the SRM Model manual, a lapse rate of .65° C per 100 m was used.

d) Critical temperature, TCRIT

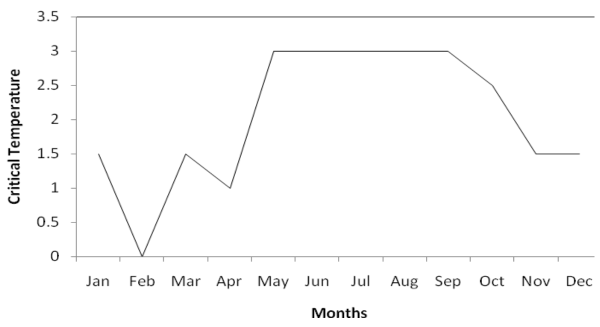

Fig. 8 plot for TCRIT 2006

e) Recession coefficient

The recession coefficient is an important feature of SRM since (1-k) is the proportion of the daily meltwater production which immediately appears in the runoff. Analysis of historical discharge data is usually a good way to determine k.

$$K_{n+1} = X.\ Q_n^{-y} \qquad (6)$$

Hence condition is satisfied and X and Y are 6.74 and .98 respectively.

f) Time Lag, L

The characteristic daily fluctuations of snowmelt runoff enable the time lag to be determined directly from the hydrographs of the past years. If, for example, the discharge starts rising each day around noon, it lags behind the rise of temperature by about 6 hours. Consequently, temperatures measured on the nth day correspond to discharge between 1200 hrs on the nth day and 1200 hrs on the n+1 day. Discharge data, however, are normally published for midnight-to-midnight intervals and need adjustments in order to be compared with the simulated values. Conversely, the simulated values can be adjusted to refer to the midnight-to-midnight periods.

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Time lag is the main criterion for temporal relation between different hydrological parameters in modeling and simulation of the catchment. The time lag for the Jhelum Basin is about taken 18 hours. Due to lack of ground data availability it is assumed 18 hours on the basis of past literature of that area.[17].

VI. RESULT AND CONCLUSION

Runoff simulation has been carried out for the Jhelum basin. The simulation was done by using snowmelt runoff modeling (SRM) for the period of (2006). The rainfall and temperature data input the model from Jhelum basin.

The simulation is acceptable and it confirms on snowmelt runoff as main water resources in region.

The catchment is free from snow in summer and it has caused the computed runoff to settle lower than measured runoff in this period,also in period of winter especially in February and March there isn't enough snowmelt that is because of low temperature and degree-days.

Computed and measured runoff values for year 2006. This shows variation in value of Computed and measured runoff values on the basis. SRM results were compared with measured runoff Simulation results were not exactly similar to measured runoff due to lack of data. At some points discharge Curve shows a rapid increase which is due to rapid change in temperature and rainfall. Though accuracy check gives value of R^2 = 0.62. Runoff computed by SRM model was not exact like Measured but was near to the measured values. So this model can be applied to Jhelum Basin in future for computation of daily runoff values.

Table 4. Simulation results of SRM model

Statistics	Run results
Measured Runoff Volume (10^6 m^3)	535.575
Average Measured Runoff (m^3/s)	16.983
Computed Runoff volume (10^6 m^3)	425.982
Average Computed Runoff (m^3/s)	13.508
Volume difference (%)	20.4628
Coefficient of determination (R^2)	0.6276

The main part of the precipitation appears as snow in winters and feeds the Jhelum basin plain. Estimation of snow cover based on the field observation is difficult in mountainous area, but the use of satellite images overcomes this difficulty. Using satellite images in Jhelum basin snow- covered area estimation is done using bands 4 and 6 of MODIS. A series of 7 images of MODIS were used for snow cover mapping.

The snowmelt runoff for year (2006) was simulated using SRM model. Graphical display of the computed runoff and the measured runoff shows that the simulation is successful, because the coefficient of determination (R^2) is 0.6276, and the volume difference is 20.4628%. By considering the obtained results, the SRM model is Appropriate model for computing the snowmelt runoff in the region and it is recommended for other parts of the Jhelum Basin.

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