Runoff simulation with snowmelt runoff modeling using RS and GIS

(Case study: Zayand-e-Rood basin)

Reza Najafzadeh, Ahmad Abrishamchi, Massoud Tajrishi

Graduate. Student of water resources engineering, Sharif University of technology, Iran

Email: reza_najafzadeh@mehr.sharif.edu

Associate professor of water resources engineering, Sharif University of technology, Iran

Email: abrisham@sharif.edu

Assistant professor of water resources engineering, Sharif University of technology, Iran

Email: tajrishy@sharif.edu

Abstract

Snow is a form of precipitation but, in hydrology it is treated somewhat differently because of the lag between when it falls and when it produces runoff, groundwater recharge, and is it also involved in other hydrologic processes. In most of mountainous and snowy regions, snowfall and snow-cover is the main source of water. To estimate the amount of water stored in snow form and how it melts, it is necessary to have an estimate of snow properties (snow water equivalent, density and depth) and snow cover area. To achieve this objective many snow measurement stations are needed. However, unnegotiability and unavailability of measurement regions in a watershed making use of these stations and also constructing such stations is very costly. Advances made in remote sensing and geographical information system has made it easy to obtain information about earth surface without need to have field measurements. Snow-cover area is one of these pieces of information obtainable from RS.

In this research snow-cover area of Pelasjan sub-basin (one of the sub-basins of Zayand-e-Rood Basin) is extracted and monitored from NOAA-AVHRR satellite images. Snowmelt runoff of Pelasjan sub-basin has been simulated by Snowmelt Runoff Model (SRM), using meteorological data and snow-cover area obtained from satellite images.

According to the results obtained, the SRM model using the RS data can accurately simulate daily runoff hydrograph of the studied basin.

1- INTRODUCTION

Over much of the worlds land areas, a significant portion of precipitation falls as snow and is stored on the surface for periods of time ranging from hours to month before melting and continuing through the land phase of the hydrologic cycle. The hydrologic interesting snow is mostly in mid- to higher latitudes and in mountainous areas where a seasonal accumulation of a snow pack is followed by an often lengthy melt period with usually little or no snowmelt. Precipitation falling as snow and sometimes rain is temporarily stored in the snowpack until the melt season begins. The hydrologist generally wants to know how much water is stored in a basin in the form of snow. The hydrologist will also be concerned with the areal distribution of snow, its condition and the presence of liquid water in it. In general, all these indicators of snow are difficult to measure and are likely to vary considerably from point to point, especially in mountainous terrain [9].

In most of mountainous and snowy regions, snowfall and snow-cover is the main source of water. To estimate the amount of water stored in snow form and how it melts, it is necessary to have an estimate about snow properties (snow water equivalent, density and depth) and snow cover area. To achieve this objective many snow measurement stations are needed. However, unnegotiability and unavailability of measurement regions in a watershed making use of these stations and also constructing such stations is very costly. Advances made in RS and GIS have made it easy to obtain information about earth surface without need to have field measurements. Snow-cover area is one of these pieces of information obtainable from RS.

Snowmelt accounts for 50 to 80 percent of the annual stream flow in many mountainous areas of the world including Sierra Nevada, Rocky, Alps, Andes and Himalayas [5]. Water derived from snowmelt is being used for the generation of hydropower, irrigation, domestic, and industrial water supply. Hence, the quantitative estimation of the extent of snow covers the stored water; the state of snow metamorphism and the intensity of snowmelt runoff are of prime importance to hydrologists and managers of water resources.

More recently, regional to global scale satellite-derived estimation of snow-cover area (SCA) became available daily and can serve as input into snowmelt runoff models. One of the most widely used of these models is the snowmelt runoff model (SRM) which was first applied to small European basins beginning in 1975 and since has been successfully used in approximately 80 mountainous basins in 25 different countries worldwide [2].

2- Description of study area

A sub basin (Pelasjan) of Zayand-e-Rood watershed was selected for this study.

Zayand-e-Rood watershed is located in the center of Iran, between 50° 02' to 53° 20' E and 31° 15' to 33° 45' N. Figure 1 shows the Zayand-e-Rood basin in Iran [11]. The average annual temperature average of Zayand-e-Rood watershed is as a function of elevation and varies from 17°C in desert regions to the lowest of 5°C in the highest regions, and the average annual precipitation of Zayand-e-Rood basin varies from 50 mm in the lowest regions to the largest 1500 mm in the highest regions [11].

There are many important cities in the Zayand-e-Rood basin such as Esfahan, Najafabad, Freidan, Daran and etc [11].

The area of the Zayand-e-Rood watershed is about 41,500 km^2 and nearly about 17000 km^2 of it is located in mountain regions. The highest point is located in the northwest with an elevation of 3974 m a.s.l. and the lowest part in the southeast with elevation of 1470 m a.s.l., and so the elevation difference is about 2500 m. Figure 2 shows the regions which have the elevation above 2000.

Fig. 1: Zayand-e-Rood watershed in Iran

About %41 of the area of Zayand-e-Rood watershed is above 2000 m. especially, all of the regions located in upstream of Zayand-e-Rood reservoir are above 2000 m elevation and the temperature of these regions usually in January and February is below zero degree. So, most precipitation fall in the upstream of the Zayand-e-Rood reservoir is in snow form.

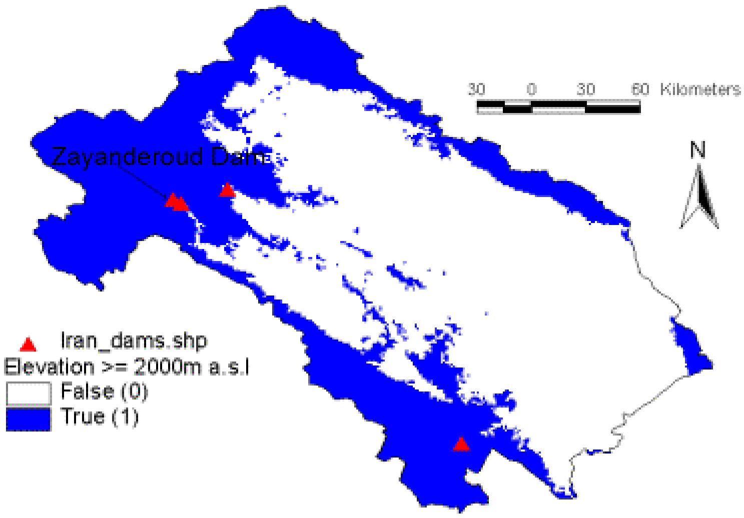

Fig. 2: Regions having elevation above 2000 m

3- Methodology and Data

The snowmelt runoff model, commonly known as SRM, is a degree-day based model for daily runoff simulation and forecasting in the mountain areas in which snowmelt is the major runoff contributor[2]. SRM has been applied around the world and its effectiveness has been proven during the last 30 years. The use of SRM for simulation and forecasting is well documented [3]. The degree-day method employed by SRM has been also proven to be very efficient in determining the average zonal or basin SWE for a specific day.

Under the assumption that there is only one SRM zone in the watershed and that there is an 18-hour time lag between the input data and the resulting stream flow, SRM calculate the daily stream flow as fallows [2, 4, and 7]:

1) $$Q_{n+1} = [C_{Sn} a_n (T_n + \Delta T_n) S_n + C_{Rn} P_n] \frac{10000}{86400} A(1 - K_{n+1}) + Q_n K_{n+1})$$

In the above equation, the average daily discharge (Q_{n+1}) [$m^3 s^{-1}$] are calculated using three factors from the preceding day (n):

(1) Snowmelt calculated from the multiplication of degree-day factor [$cm\,^oC^{-1}\,d^{-1}$] and representative zonal degree-days ($T + \Delta T$) [$^oC\,d$] which is weighted by the ratio (S) of the SCA to the total basin area (A) [km^2].

(2) Precipitation (P) contributing to runoff [cm].

(3) Discharge from the preceding period (Q).

($T + \Delta T$) represents extrapolated degree-days calculated at the average hypsometric elevation of the zone from the degree-days measured at the meteorological station.

These runoff-controlling factors are adjusted by three coefficients: c_s and c_r are the snowmelt and rainfall runoff coefficient, respectively, that express water losses as a ratio of runoff to precipitation and k is a recession coefficient indicating the decline of discharge over time for periods without snowmelt or rainfall. The factor (10000/86400) represents a conversion from ($cm\ km^2 d^{-1}$) to (4 ,2] (m^3 / s , and 7].

If there are multiple zones, as were used here, Eq. 1 is applied separately to each zone and the discharges are assumed. For lag time other than 18 hours, SRM adjusts the input data appropriately. In addition to the above variables and parameters, parameters such as critical temperature and rainfall contributing area also need to be considered in SRM model [2, 4, and 7].

Sub basin area is also an important characteristic for modeling. For exacting the boundary of sub basin the digital elevation model (DEM) [1/25000] were used and the area of sub basin was determined. The area of Pelasjan sub basin is 1634 km^2; the elevation range is from 2120 m to 3903 m, also that hypsometric elevation is 2460m [1].

3-1- Determination of SCA variation

The shape of depletion curve (changes in SCA over time during season) depends on several factors including initial snow reserves and meteorological conditions as well as intermittent precipitation during the melting season [7]. The snow depletion curve required as input in SRM considers only the depletion of 'permanent' snow cover which is present from the start of the simulation (assumed here to be March 1^{st}). Transient snowfall that occurs during the snow ablation season is stored in SRM as precipitation, and therefore, sudden and short-lived increases in SCA should not be included in the snow depletion curve [7].

Remote sensing is an important source of snow-cover area information for input to the snowmelt runoff model (SRM) and other snowmelt models [6]. In this research, the NOAA-AVHRR (NOAA-11) satellite images were use. After Geo-Reference and processing these images with Ilwis, snow-cover area of Pelasjan sub-basin is extracted. Table 1 describe snow cover product from NOAA-AVHRR images.

Table-1: snow covers area [1]

Date	Snow cover area (km^2)	Snow covers area (%)
Jan-16-1993	1634.0	100
Jan-24-1993	1634.0	100
Feb-10-1993	1634.0	100
Feb-17-1993	1634.0	100
March-23-1993	1402.819	85.85
March-28-1993	1097.806	67.18
March-31-1993	991.2933	60.67
April-9-1993	559.1911	34.22

3-2- Data

In addition to zonal daily SCA values, zonal daily temperature and precipitation data are also needed to run SRM model [2, 10]. In the Pelasjan, there is a synoptic station located in city of Daran that measures the daily temperature and daily precipitation (1992-93 year value), These data were used for running the SRM model. The discharge of sub basin Pelasjan measurement is made in the Skandary station. Also there are four stations that measure snow water equivalent and depth values.

3-3- Parameter

The parameter of SRM is degree-day factor, temperature lapse rate, critical temperature, rainfall contributing area, recession coefficient, time lag, rain and snow runoff coefficients. [2]

If temperature stations at different altitudes are available, the lapse rate can be predetermined from historical data. Otherwise, it must be estimated by comparison from other basins or with similar climatic conditions. In SRM simulations, a lapse rate of 0.65°C per 100 m is usually employed. In this research temperature lapse rate was determined using the 35 stations with different elevations [2].

Degree-day factor converts the number of degree days above critical temperature into snowmelt depth in cm. Table 2 show the variation of degree-day factor from January to march

Table-2: Degree-day factor [1]

Date	degree-day factor
Jan-12- 1993	0.226
Feb-9- 1993	0.340
March-8- 1993	0.401

SRM only needs the critical temperature in the snowmelt season (unless a year round computer run is made) in order to decide whether precipitation, immediately contributes to runoff (rain), or, if $T < T_{CRIT}$, whether snowfall took place. When SRM was applied in the Alpine Basin Dischma, T_{CRIT} started at + 3°C in April at the beginning of snowmelt and diminished to + 0.75°C in July [2]. In present research, a critical temperature of 2°C was assumed and kept constant during the year.

4- Result

Using the above hydrological and meteorological parameters and daily snow cover estimation from basin with digital image processing of satellite remote sensing data. The discharge hydrographs was computed for the Pelasjan river basin for the entire snow melt period, September 23 of the year 1992 to September 22 of the year 1993. Figure 3 shows the hydrographs of measured and simulated discharge for the above period.

The analyses of the above figure indicate good simulation between measured and computed discharge.

To analysis the performance of the model, linear regression analyses has been made. Results are shown in Equation 2 and figure 4. The correlation coefficient (r) of 0.96 indicates the existence of a high degree of correlation between measured and computed discharges.

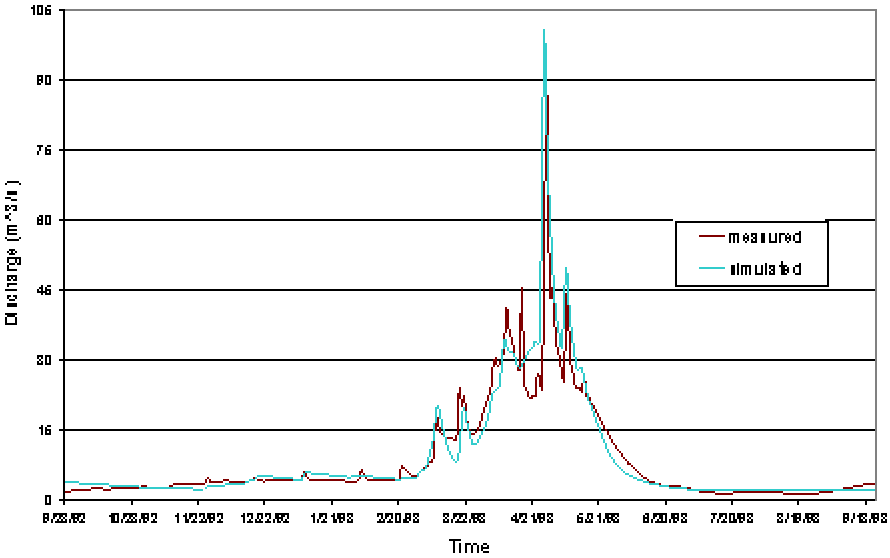

Fig. 3: Measured and simulated discharges hydrographs for year 1992-93[1]

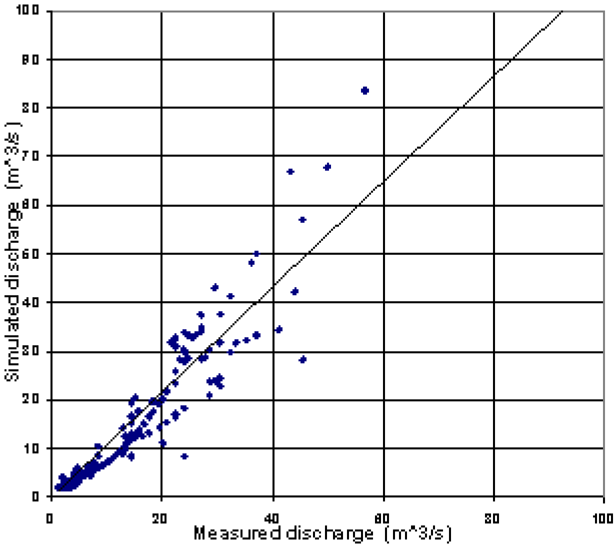

Fig. 4: Scatter plot and linear regression fit for measured and simulated discharges of the Skandary station for year 1992-93

$$y = 1.0816x \ (r^2 = 0.9186) \qquad (2)$$

SRM uses two well-established accuracy criteria, namely, the coefficient of determination, R^2, and the volume difference, D_V [2].

The coefficient of determination and volume difference are calculated as follows [2]:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(Q_m - Q_s)^2}{\sum_{i=1}^{n}(Q_m - \overline{Q})^2} \qquad (3)$$

$$D_V = \frac{V_m - V_s}{V_m} \times 100 \qquad (4)$$

Where:

Q_m : measured daily discharge

Q_s : Daily discharge

$\overline{Q}$: Average daily discharge for the simulation year or simulation season

n = number of daily discharge values

D_V = percentage difference between the total measured and simulated runoff (%)

V_m = Measured runoff volume

V_s = simulated runoff volume

For the simulation of the Pelasjan watershed, the coefficient of determination (R^2) is 0.91 and the volume difference (D_V) is 4.6 (Table 3).

Table-3: Simulation results for the Pelasjan sub basin (1992-93) [1]

Statistics	Value
Measured runoff volume(MCM)	261.5
Simulated runoff volume(MCM)	273.4
Average measured runoff(m^3s^{-1})	8.3
Average simulated runoff(m^3s^{-1})	8.7
Volume difference (%)	-4.6
Coefficient of determination (R^2)	0.91

According to the results obtained, the SRM model using RS data can accurately simulate daily runoff hydrograph of the studied basin.

5- Reference

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