Available online at www.jrors.yazd.iau.ir

Journal Of Radar and Optical Remote Sensing and GIS

JRORS 2 (2022) 23–34

Simulation of Snowmelt Runoff by (SRM) Hydrological Model Using MODIS Satellite Imagery

Ehsan Fouladvand[a*]

[a]*Master of Science in Remote Sensing Engineering, Graduate University of Advanced Technology, Kerman, Iran*

Received 9 April 2022; Revised 6 June 2022; Accepted 16 June 2022

Abstract

Prediction and estimation of runoff from snowfall and a quantitative understanding of its various production processes is considered as one of the important topics in hydrology. Therefore, the quantitative and qualitative achievement of it with a systemic approach in this regard is of importance since it forms the basis of studies of construction projects in various fields of development and exploitation in water resources and hydraulic structures and other environmental areas in the watersheds. Regarding the fact that snow cover represents the amount of stored water, so spatial-temporal (*spatiotemporal*) monitoring of snowmelt runoff is of great importance in hydrological forecasting in this region. The determination of the amount of snowmelt runoff is a function of regional characteristics and the availability of regional data. Therefore, in order to achieve this, ground operation and the creation of a denser network of snow survey stations are needed, which is almost impossible and is not economical. Therefore, in this study, in order to simulate runoff and estimate the share of snowmelt runoff in Marboreh River, simultaneously, optical satellite data and hydrological modelling of runoff are used as advantages. So that, snow product of the 8-day MODIS at 500-meter resolution was used to calculate the snow cover. Finally, the results obtained from runoff simulation by the coefficient of determination and subtracting volume, which were obtained at 0.93 and 3.48 respectively, indicate the high accuracy of the simulation for the area under study.

***Keywords**:* Runoff, Hydrology, Snow Cover, Simulation, MODIS

1. Introduction

Water resources have been vital to the human population throughout the history as used for drinking, irrigation, hydropower, and industrial etc (Sofi et al. 2021). Advancements in satellite imagery and computer analysis have made it possible to develop a sensible, precise, and more importantly, it gives, uniform data set for hydrological investigations (Ashokan et al. 2020) Now, advancement in Remote sensing and GIS has gone to such an extent that we can compute albedo (Hofierka and Onačillová, 2022). Integration of biophysical and socio-economic data can be made in the GIS environment and

* Corresponding author Tel: +98- 9140551981.
Email address: fouladvand.e@yahoo.com

can be utilized to develop a good database for difficult terrain. As opposed to the regular methodology, these devices enable the combination of multi-spectral spatial information and their presentation in an understandable format i.e., map. Inaccessibility in the Himalayan region leads to the failure of the conventional method of monitoring the snow cover area due to the lack of making field measurements in snow cladded mountains (Sood et al. 2020). The ice exposed surface of the glacier increases over time, leading to greater runoff. A melting glacier contributes more melt water as the ablation progresses Remote sensing technologies and spatial information systems are two new technologies that are increasingly used in day-to-day snow hydrology. These technologies can be used for snow analysis and meteorological sensed data, performing necessary processes, obtaining input variables for hydrologic models and displaying model output. With the advancement of technology in the field of remote sensing sensors, the equipment was built that was stable in bad weather. One of the important applications of remote sensing in hydrology is to obtain snow data, such as snow-covered area and snow equivalent water, which is very important for predicting snowmelt runoff as simultaneous and instant (Tekeli, et al. 2005). The water stored in the snow plays an important role in the hydrological balance cycle in many regions of the world, especially in mountainous areas. Also, the monitoring and modelling of snow accumulation and melting, especially in mountainous areas, are subject to some limitations due to the variability of snow characteristics and the limited availability of ground based hydrologic data (Parajka, and Bloschl, 2008). The snow-covered area is an important parameter for the hydrological cycle and climatology. Reflection caused by high whiteness of snow causes the snow-covered area to reflect most of solar energy. Due to high heat capacity of snow, snow-covered area protects the soil from the atmosphere and reduces the warming process during spring. Therefore, with the influence of energy absorption and warming of the basin, snow has a direct role in the down/large-scale atmospheric circulation patterns. Snow cover and soil moisture are the most important variables in the heat and moisture transfer process between the earth and the atmosphere. The presence of snow in the basin has a significant influence on the moisture levels of the surface and as a result the flow of the runoff (Maurer et al. 2003).

2. Material and Method

2.1. Study Area

The Marboreh-Tireh River basin, located in Lorestan province, with a longitude of 47.8086 degrees to 51.2025 degrees, and latitude of 32.6045 degrees to 34.7014 degrees, and with an area of 6860.906 kilometers. The Marboreh River is caused by the confluence of the sub-basin of the Kamandan and the Dareh Takht. Under gravity force, the river water flows from Azna city with an elevation of 7314 meters toward Doroud city with an elevation of 7054 meters. The minimum elevation in the Kamandan and Dareh Takht basins is 2100 and 1980 meters, respectively. At last, this river is merged with the Tireh Rood and Sabzeh Rood River in Doroud city and then flows out of it.

Figure 1. The study area

3. Data Collection

3.1. Meteorological and Hydrological Data

Average daily air temperature
Daily precipitation
Daily flow rate (the daily discharge)

3.2. Satellite Data

MODIS images, 8-day snow product, 500 m spatial resolution.

3.3. Geographic and Topographic Data

Digital Region Model
Aspect-slope map of area
Land use map of area
Map of the soil group classifications of area

3.4. Snowmelt Runoff Model (SRM)

The snowmelt runoff model (SRM) has been presented by Swiss researchers for managing water resources, irrigation and water storage. The basis of this model is the degree-day method. The snowmelt runoff model has been tested by the World Meteorological Organization for simulation, which has been identified as the most accurate model for simulating snowmelt in comparison with other models (Martinec, Rango, and Major, 1983). In this model, runoff from rainfall and snow melting is calculated daily and added to the calculated base flow.

The information inputs to the model include basin characteristics and elevation areas, variables and parameters that are described below.

3.5. Basin Characteristics and Elevation Areas

Snow depth in areas with higher altitude is usually greater than other areas due to evaporation and less melting. Physical and geometric characteristics of the drainage basin and the type and extent of vegetation cover at its surface have a significant effect on the distribution of precipitation and the determination of the hydrological parameters of the area. By affecting the energy absorption and warming of the basin, snow has a direct role in the small/large-scale atmospheric circulation patterns. Snow cover and soil moisture levels are the most important variables in the process of heat transfer and moisture between the earth and atmosphere. The boundary of the basin is prepared using topographic maps and contour line is plotted on it. Then, the basin is divided into elevation areas based on the altitude and the area of the basin, and the depth-area curves are plotted for them and the effective parameters in the snow melting area are calculated at the hypsometric mean height of each area. The hypsometric altitude of each area can be determined from the hypsometric curve and the temperature of the base station is transmitted to these altitudes (Vazife Dost, 2010).

3.6. Degree-Days Factor

The Degree-days factor is defined as the amount of the depth of snow melted to the degree-day, and is expressed in the form of relation (6) (Martinec, Rango, and Major, 1983).

$M=\alpha.T$ (1)

α: Degree-days factor

M: daily snowmelt depth

Degree-day ratios can be evaluated by comparing degree-day values with the daily decrease in the snow water equivalent which is measured by radioactive snow gauge, snow pillow or a snow lysimeter. In the absence of data, the degree-day factor can be calculated using the empirical relation (7) (Martinec, Rango, and Major, 1983).

$A=1.1*(\rho s/\rho w)$ (2)

Where:

ρs = Specific weight of snow

ρ w = Specific weight of water

3.7. Precipitation

Given that precipitation data recorded by rain gauge stations are in the form of precipitation point, it requires the generalization of precipitation data to the basin area so that the daily average precipitation data can be extracted for the model and, on the other hand, generalizing precipitation point to the area is difficult and complex in mountainous basins.

3.8. Temperature Degree

The temperature is transmitted by the temperature gradient to the hypsometric mean elevation of the studied basin. For this purpose, at first the digital elevation model (DEM) of the region was prepared and then divided into zones with intervals of about 500 meters in 5 elevation zones. Based on the area of each zone, the hypsometric mean elevation basin is calculated and temperature is transmitted to it.

$T= (Tmax + Tmin)/2$ (3)

$\Delta T=\lambda*(H-H'')*1/100$ (4)

Where:

λ: temperature lapse rate [°C per 100 m]

H: hypsometric mean elevation

3.9. Time Lag

The characteristics of daily runoff fluctuations can be determined through the time lag and 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 nthday correspond to discharge between 12 hrs. on the nth day and 12 hrs. on the n+1 day. Time lag is the most important basis for the time relationship between various hydrological parameters in modelling and simulation.

$$T = \frac{L^{\wedge}0.8(S+1)^{\wedge}0.7}{1900Y^{\wedge}0.5} \quad (5)$$

To calculate the time lag, empirical relationships such as the method of calculating the time lag, the mean gradient and the length of the main river are the most important parameters (Martinec, Rango, and Major, 1983).

L: river length

Y: basin means elevation (mean elevation of the basin)

L=6h	0.5I+0.5I	Qn+1	(6)
L=12h	0.75I+0.25I	Qn+1	(7)
L=18h	I	Qn+1	(8)
L=24h	0.25I+0.75I	Qn+1	(9)

MODIS satellite snow cover images for hydrological applications are desirable due to temporal and spatial resolution and the adequate accuracy of providing an acceptable map by these images (Martinec, Rango, and Major, 1983). MODIS images are used in hydrology due to the spatial and temporal resolution, and the ability of snow/cloud discrimination and widespread global coverage and the availability of these images (Hall and Salomonson, 2006).

In 2005, Burbusque et al. concluded that the combination of snowmelt runoff and MODIS snow cover would work very well for Himalaya. Lee et al. (2005) state that the snowmelt runoff model offers acceptable accuracy through the images of the MODIS.

The MODIS sensor, in contrast to many other sensors, has a higher resolution and more spectral bands, while cloud discrimination is better in the images of this sensor; because of this in terms of the cloud/snow discrimination there is fewer problems with an image of this satellite.

In this research, 8-day snow product is used to determine the snow-covered area which is a data from the 8-day snow cover, that is made using daily data from 2 to 8 days. When there are no data for less than 8 days in the 8-day period for any reason, such as data loss on the satellite or any other reasons, data less than 8 days (2 to 7 days) are used to determine the snow covered area. But, if in the 8-days period, only one-day data is available, the 8-day snow cover will not be produced. To produce 8-day snow data of MODIS, the goal of the algorithm is to maximize the amount of snow pixels and minimize the amount of cloud pixels. In order to determine the daily area of snow, 8-day data was interpolated.

3.11. Runoff Coefficient

At the beginning of the snowmelt season, the losses are very small, and in the next stages, when the soil becomes exposed and vegetation grows, losses are increasing due to evapotranspiration and interception. At the end of the snowmelt season, the direct channel flow from the remaining snowfields and glaciers may be common in some basins which lead to a decrease of losses and to an increase of the runoff coefficient. In addition, Runoff coefficient is usually different for snowmelt and for rainfall.

$$C=R/P \quad (10)$$

$R=\frac{(P-0.2S)}{(P+0.8S)}$ (11)

S=(1000/CN)-10 (12)

Where, P: Precipitation

S: Maximum soil moisture retention

And then, using the equation below, turns into a daily discharge.

$Qn=Kn*Q_{n-1}+(1-Kn)*(10000/86400)*\sum[(CS_{i,n}*a_{i,n}*(T_{i,n}+\Delta T_{i.n})*S_{i,n}+CR_{i,n}*P_{i,n}]*A_i$ (13)

Where:

Q: average daily discharge

C: runoff coefficient expressing the losses as a ratio (runoff/precipitation)

a = degree-day factor indicating the snowmelt depth resulting from 1 degree-day

S = ratio of the snow covered area to the total area

P = precipitation contributing to runoff

A = area of the basin

3.12. Assessment of the Model's Accuracy

The SRM model uses a qualitative criterion, observing the matching of hydrographs and two accuracy criteria; namely, the coefficient of determination, R2 and the volume difference, Dv. The coefficient of determination is computed as follows:

$R^2=1-\frac{\sum(Qi-Q"i)^2}{\sum(Qi-Q'i)^2}$ (14)

$Dv=100*\frac{Vr-V'r}{Vr}$ (15)

Where,

Qi=measured daily discharge

Q"i =simulated daily discharge

Q'i=average measured discharge

Vr= measured runoff volume

V'r =computed runoff volume

Conclusions:

By calculating the area of each zone, the hypsometric curve of the studied basin was extracted and temperature was transmitted by the temperature gradient to the hypsometric mean elevation.

In order to calculate the average daily precipitation in the basin concerned, the fitting of the polynomial function method is used; also, to increase its accuracy and determine the type of function and its degree, the statistical test and Fisher test are used so that the best kind of function is achieved in order to generalize precipitation data. The rain gauge stations such as Azna, Aligudarz, Doroud, Rahimabad, Boroujerd, Vennaei, Cham Zaman, DarrehTakht, Kamandan, Cham Chit, Tireh, AbBarik, Khomein, Kakareza, Dehno, Shamsabad were used to estimate daily precipitation in the basin.The determination of the curve numbers requires the preparation of the land use map of the basin and the mapping of the soil type and then the classification of the soil in the hydrological groups; In fact, it is the preparation map of the soil hydrology group and the preparation of the boundaries of each group and the relationship between them.

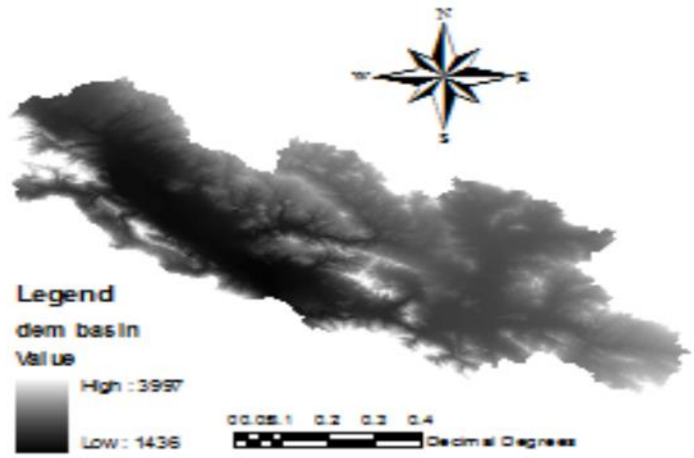

Figure 2. Digital Elevation Model Map

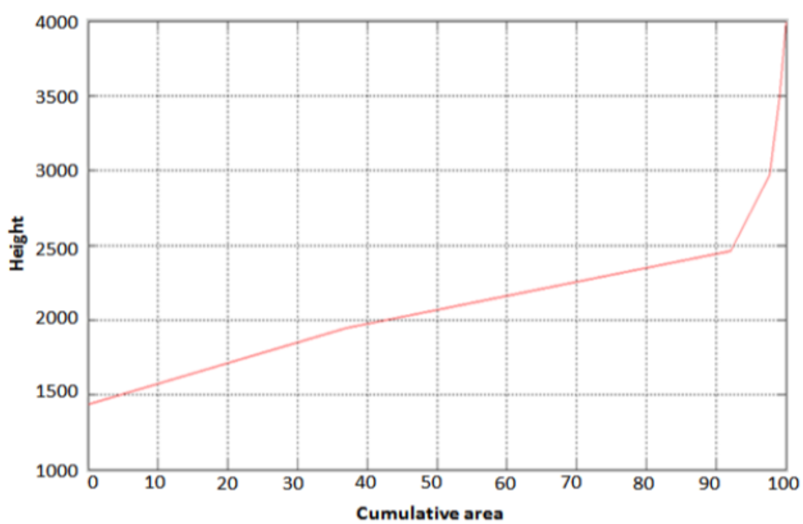

Figure 3. Hypsometric curve of the studied basin

Table 1. Basin

Elevation zones	Area of the basin or zone	Average of the basin or zone
1436-1948.2	2581.96	**1692.1**
1948.2-2460.4	3781.21	**2204.3**
2460.4-2972.6	388.338	**2716.5**
2972.6-3484.8	97.232	**3228.7**
3484.8-3997	12.166	**3740.7**

Finally, considering that each soil group consisted of several types of land use in the region, weighted mean was taken from the curve numbers based on its area.

$$CN_{avg}=\frac{\sum Ai*CNi}{\sum Ai} \quad (16)$$

Where: A: area of the land use

The land use map of the studied area was classified into 10 different land uses.

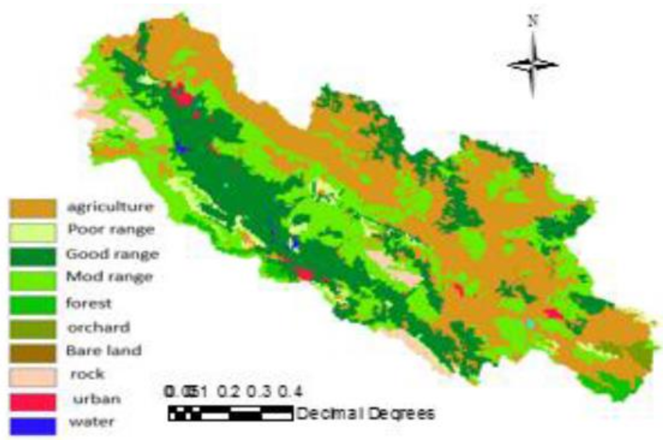

Figure 4. Land use map of the studied basin

In order to prepare a map of the hydrologic soil group classifications in the studied basin, the hydrologic soil group map of area was determined after preparing the soil map of area based on the classification of soil conservation service.

Table 2. Hydrologic soil group classification

Type	Permeability	Rate(in/h)
A	very rapid	**<0.30**
B	moderate	**0.15_0.30**
C	slow	**0.05_0.15**
D	*very slow*	**0_0.05**

With regard to the type of soil in the studied area and the permeability rates of its soil, hydrologic soil group map was prepared for the area and it was observed that the region consisted of 3 groups of B, C, and D.

Figure 5. Hydrologic soil group map

4. Determining the Coefficient of Curve

After calculating and obtaining the required data and the correlation between them, the CN coefficients were extracted.

Table 3. Curve number

Land use	A	B	C	D
agriculture	67	78	85	**89**
bare land	68	79	86	**89**
water	100	100	100	**100**
Mod range	49	69	79	**84**
Poor range	68	79	86	**89**
forest	38	63	75	**82**
urban	77	85	90	**92**
Good range	90	61	74	**80**
orchard	43	65	76	**82**

According to the area of each land use in each soil group, the final curve coefficient was calculated.

Table 4. Calculation of the final CN of each land use

Land use	B	C	D	Area (km^2)	CN
agriculture	680.51	1722.14	102.46	2505.11	**83.26**
bare land	2.6	2.6		5.2	**82.5**
water	8.62	1.80	4.21	14.63	**100**
Mod range	517.5	886.64	455.55	1859.69	**77.44**
poor range	29.66	73.99	101.25	204.9	**86.47**
forest		60.75	51.93	112.68	**78.23**
urban	44.5	3.40	15.24	63.14	**86.96**
good range	814.86	558.66	344.07	1737.59	**69.09**
orchard	9.22	75.60	1.20	86.02	**74.90**

Finally, the total basin CN was extracted through weighted mean.

The process of simulation of snowmelt runoff in the studied area was implemented for 2003-2002 years and finally the simulation accuracy was calculated by the coefficient of determination and the volume difference. According to the hydrograph simulation, it was observed that the highest runoff was in months, such as March and May, which has been one of the reasons for the precipitation in these months.

Finally, after calculating all parameters and variables described, the final result of the simulation process of snowmelt runoff was obtained and evaluated by the parameters of the runoff coefficient and the volume difference.

Table 5. Final Results

Measured runoff (m^3/s)	**5263.3**
simulated runoff (m^3/s)	**5453.5**
coefficient of determination R^2	**0.93**
D_V	**3.48**

The results indicate that the model has been able to simulate the snowmelt runoff with high accuracy in 2002-2003. It is also shown graphically in Figure 11.

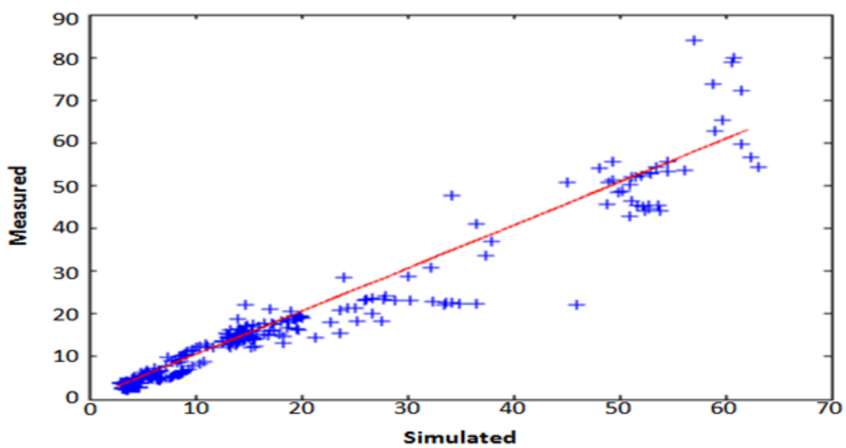

Figure 6. Scatter plot of simulated and observational data

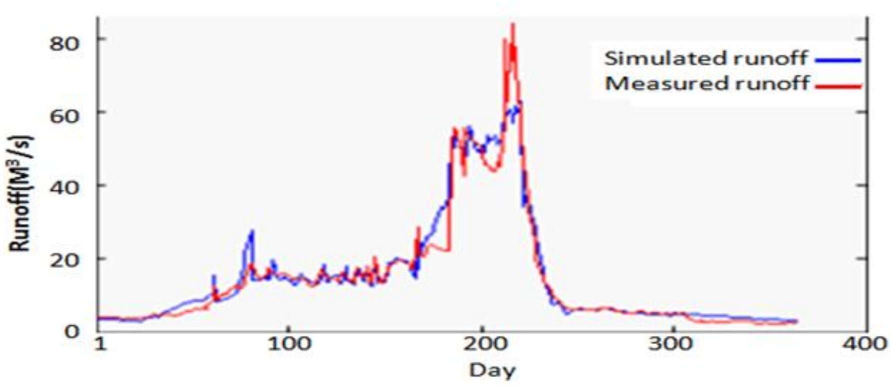

Figure7. Graph of measured and simulated Runoff

5. Sensitivity Analysis of Model Variables

In order to investigate and analyze the sensitivity of the model parameters, 50% and 30% of the values of each parameter was added and subtracted, and for each change in each of the variables, the snowmelt runoff process was simulated.

Table6. Investigating the sensitivity of rainfall runoff coefficient

Parameter	Parameter changes	Runoff changes	Total changes
	Cr+50%	0.4996	
Rainfall runoff coefficient	Cr+30%	0.3013	**1.0153**
	Cr-30%	-0.294	
	Cr-50%	0.5084	

Table7. Investigating the sensitivity of snowmelt runoff coefficient

Parameter	Parameter changes	Runoff changes	Total changes
	Cr+50%	0.0197	
Snowmelt runoff coefficient	Cr+30%	0.0134	**0.016**
	Cr-30%	-0.0054	
	Cr-50%	-0/0117	

6. Conclusion

In conducting research projects in the field of hydrologic issues, researchers are generally forced to provide experimental models or calibrate existing experimental models with their regional conditions due to the lack of adequate and accurate data in drainage basin. Due to the effects of physical, geological, pedological, vegetation properties, rainfall regime, geometric conditions and physical properties of main and sub canal of the drainage basin, models of runoff and flood simulation are important. On the other hand, the result of this study showed that in basin lacking snow measurement data, the snow-covered area can be obtained using satellite images because it provided acceptable results in simulating the snowmelt runoff by using the model in the studied area. Finally, due to the fact that in western Iran and especially in Oshtrankouh mountains located in Lorestan province, with high potential for snow accumulation and precipitation, this model was used in Oshtoranko mountainous region in this study. Based on high accuracy obtained in the study, it was determined, on the other hand, that the snowmelt runoff model (SRM) in mountainous areas has also very good accuracy, as well as the MODIS images with regard to availability, acceptable spatial and temporal resolution, accuracy of the mapping and its ability to reduce the effect of cloud pixels, these images were used in simulation. It was concluded that very good results can be reached using satellite imagery and GIS in hydrologic models such as snowmelt runoff simulation. Also, in this study, by comparing the resulted changes in runoff amount, it was concluded that the runoff coefficient has a higher sensitivity as compared with the other variables. Another result is that in comparing the rainfall runoff coefficient and snowmelt runoff coefficients, as shown in tables (4-15) and (4-16), the rainfall runoff coefficient has a higher sensitivity to the snowmelt runoff coefficient. Therefore, achieving high accuracy in simulation by the SRM model requires accurate determination of rainfall runoff coefficient.

References

Ashokan, A., Anitha, J., Ciobanu, M., Gabor, A., Naaji, A., & Hemanth, D. J. (2020). Image processing techniques for analysis of satellite images for historical maps classification-An overview. *Applied Sciences, 10*(12), 4207.

Bales, R. C., & Cline, D.(2003). Snow hydrology and water resources (Western United Sates). In *Handbook of Weather, Climate and Water; Atmospheric Chemistry, Hydrology, and Societal*

Impacts, 443-459.

Bloschl, G. (1991). The Influence of Uncertainty in Air Temperature and Albedo on Snowmelt. *Hydrology Research, 22*(2), 95-108.

Dozier, J., Schneider, S. R., & McGinnis Jr, D. F. (1981). Effect of grain size and snowpack water equivalence on visible and near-infrared satellite observations of snow. *Water Resources Research. 17*(4), 1213-1221.

Tekeli, A. E., Akyürek, Z., Şorman, A. A., Şensoy, A., & Şorman, A. Ü. (2005). Using MODIS snow cover maps in modeling snowmelt runoff process in the eastern part of Turkey. *Remote Sensing of Environment, 97*(2), 216-230.

Prasad, V. H., & Roy, P. S. (2005). Estimation of Snowmelt Runoff in Beas Basin, India. *Geocarto International, 20*(2), 41-47.

Hofierka, J., & Onačillová, K. (2022). Estimating visible band albedo from aerial ortophotographs in urban area. *Remote Sensing, 14*(1), 164.

Parajka, J., & Bloschl, G. (2008), The value of MODIS snow cover data in validating and calibrating conceptual hydrologic models. *Journal of Hydrology, 358*(3-4), 240-258.

Lee, S., Klein, A. G., & Over, T. M. (2005). A comparison of MODIS and NOHRSC snow-cover products for simulating streamflow using the Snowmelt Runoff Model. *Hydrological Processes: An International Journal, 19*(15), 2951-2972.

Martinec, J., Rango, A., & Major, E. (1983). *The Snowmelt-Runoff Model (SRM) user's manual* (No. REPT-83B0251).

User's Manual. Edited by Enrique Gómez-Landesa & Max P. Bleiweiss This publication is an updated edition of the Snowmelt Runoff Model (SRM) User's Manual featuring the new computer program WinSRM Version 1.11

Milner, A. M., Khamis, K., Battin, T. J., Brittain, J. E., Barrand, N. E., Füreder, L., … & Brown, L. E. (2017). Glacier shrinkage driving global changes in downstream systems. *Proceedings of the National Academy of Sciences, 114*(37), 9770–9778.

Maurer, E. P., Rhoads, J. D., Dubayah, R. O., & Lettenmaier, D. P. (2003). Evaluation of the snow-covered area data product from MODIS. *Hydrological Processes, 17*(1), 59–71.

Martinec, J., & Rango, A. (1986). Parameter values for snowmelt runoff modelling. *Journal of Hydrology, 84*(3-4),197-219.

Hall, D. K., & Salomonson, V. V. (2006). MODIS Snow Products User Guide to Collection 5 George A. Riggs. http://modis-snow-ice.gsfc.nasa.gov/ sugkc2.html.

Rezai, Y., & Mobasheri, M. (1385). Image satellite. Num 8-40, Tehran university.

Saberi, N., Homayouni, S., & Motagh, M. (2013). Snow Runoff Modeling Using Meteorological, Geological and Remotely Sensed Data. *Intl. J. Humanities, 2*, 79-100.

Sood, V., Singh, S., Taloor, A. K., Prahar, S., & Kaur, R. (2020). Monitoring and mapping of snow cover variability using topographically, derived NDSI model over north Indian Himalayas during the period 2008-19. *Applied computing and geosciences, 8*, 100040.

Stanzel, P., Kahl, B., Haberl U., Herrnegger, M., & Nachtnebel, H. P. (2008). Continuous hydrological modelling in the context of real time flood forecasting in alpine Danube tributary catchments. In I*OP Conference Series: Earth and Environmental Science*. 4(1), p. 012005). IOP Publishing.

Sofi, M. S., Rautela, K. S., Bhat, S. U., Rashid, I., & Kuniyal, J. C. (2021). Application of geomorphometric approach for the estimation of hydro-sedimentological flows and cation weathering rate: towards understanding the sustainable land use policy for the Sindh Basin, Kashmir Himalaya. *Water, Air, & Soil Pollution 232*(7), 280.

Vazife Dost, M. (2010). Runoff snowmelt in polroud river, Gilan.