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USING SATELLITE IMAGES AND SRM HYDROLOGICAL MODEL FOR EVALUATING RUNOFF RESULTING FROM SNOWMELT IN NAVROOD BASIN

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Original scientific paper
Determining snowmelt runoff share of watershed basins with snow and wet snow regimes is one of the main concerns of the experts in water resources field, assessment of which has been done so far with difficulties and high rate of error due to lack of snow survey and weather stations in highlands of basin and use of traditional surveying methods. Lack of integrated management system in watershed basins, flood control, soil erosion, drought prediction and water supply are among problems the impacts of which, from a microclimatic perspective, can effectively be dealt with through modelling of snowfall surface features. In this research, satellite images of snow cover and temperature of MODIS sensor were received in a 9-year period as from Oct. 16 until Apr. 24 from 2000 to 2009; these images were processed in ERDAS Imagine software through codes provided by MATLAB software and then the data of snow cover and ground surface temperature were extracted, their graphs were drawn and the data changes regime in the related period was investigated. In the next stage, the data as well as the variables and the required parameters from the ground stations existing in the basin were entered into Snowmelt Runoff Modelling (SRM) hydrological model and the model was measured for the water year 2000 ÷ 2001. Data of satellite images were also received and processed by the model. The results showed a 12 percent share in snowmelt runoff as compared to the total volume of flow in this year and comparison of changes in snow cover surface area and surface temperature obtained from satellite data with the amount of water release confirms that snowmelt runoff has a noticeable role in Navrood water in such a way that with decrease of snow level and increase of snow temperature, the basin water release increases. Investigation of data related to discharge – snow cover surface, temperature – snow cover surface and temperature – discharge indicated that data affect each other. Increased snow cover surface corresponds with decreased discharge, increased snow cover surface corresponds with decreased temperature and in temperature – discharge diagram; increased temperature is directly related to increased discharge.

Keywords: *Navrood watershed basin, snowmelt runoff modelling hydrological model, satellite images of temperature, snow cover*

Uporaba satelitskih snimaka i SRM hidrološkog modela za procjenu otjecanja nastalog otapanjem snijega u slivu Navrood

Izvorni znanstveni članak
Utvrđivanje udjela otjecanja otopljenog snijega u riječnim slivovima s režimima snijega i mokrog snijega, jedan je od glavnih preokupacija stručnjaka u području vodnih resursa. Procjena koja je do sada rađena s teškoćama i visokom stopom pogreške bila je uvjetovana nedostatkom istraživanja snijega i vremenskih stanica na visoravnima sliva i korištenjem tradicionalnih geodetskih metoda. Nedostatak integriranog sustava upravljanja u riječnim slivovima, kontrole poplava, erozije tla, predviđanja suša i vodoopskrbe su između ostalog problemi čiji se utjecaji, iz mikroklimatske perspektive, mogu učinkovito odrediti modeliranjem površinskih značajki napadanog snijega. U ovom istraživanju, satelitske slike snježnog pokrivača i temperature MODIS senzora su zaprimljeni u 9-godišnjem razdoblju, od 16. listopada do 24. travnja 2000. ÷ 2009.; ove slike su obrađene u ERDAS Imagine softveru preko kodova danih MATLAB softverom, a zatim su izlučeni podaci snježnog pokrivača i temperature površine tla, nacrtani su njihovi grafovi i istraživani su podaci režima promjena u navedenom razdoblju. U idućoj fazi, podaci, kao i varijable te traženi parametri iz zemaljskih postaja koje postoje u slivu ušli su u Modeliranje hidrološkog modela otjecanja otopine snijega (SRM), a model je mjeren za vodnu godinu 2000. ÷ 2001. Podaci satelitskih snimki također su primljeni i obrađeni modelom. Rezultati su pokazali 12-postotni udio otjecanja otopljenog snijega u ukupnoj količini protoka u ovoj godini, a usporedbe promjena u području površine snježnog pokrivača i površinske temperature dobivene iz satelitskih podataka s količinom oslobođene vode potvrđuje da otjecanje otopljenog snijega ima primjetnu ulogu u vodi Navrood na takav način da se smanjenjem razine snijega i povećanjem temperature snijega, sliv osobođene vode povećava. Istraživanje podataka vezanih za istjecanje – površina snježnog pokrivača, temperatura – površina snježnog pokrivača i temperatura – istjecanje pokazalo je da podaci utječu jedni na druge. Povećana površina snježnog pokrivača sukladna je smanjenom istjecanju, povećana površina snježnog pokrivača sukladna je smanjenju temperature i u dijagramu temperatura – istjecanje; povećana temperatura izravno je povezana s povećanim istjecanjem.

Ključne riječi: *modeliranje hidrološkog modela otjecanja otopljenog snijega, riječni sliv Navrood, satelitske snimke temperature, snježni pokrivač*

1 Introduction

According to surveys, almost 60 % of surface waters and 57 % of groundwater in the country are located in areas with high rate of snowfall, and are fed by snowmelt [1]. High level of albedo in snow along with its high surface extension has great impact on earth's radiation budget. Systematic monitoring of snow cover surface highlights the evaluation of resultant snowmelt levels. Generally snow accumulation and snowmelt are usually modelled using ground observations. In order to develop effective and reliable hydrological models and improve predictions, more accurate and cost-effective methods are necessary for assessing snow cover surface. Thus, nowadays in the process of efficient management of water resources, application of remote sensing data with the aim of obtaining precise information from snow cover is performed in an operational manner.

Initial attempts to determine the extent of snow cover and snow line position focused on aerial images [2]. Because of high albedo in snow, snow cover extent was obtained easily by first images taken by TIROS-1 weather satellites. Data obtained from weather satellites were useful in determining boundaries, snow cover surface and changes in snow layers due to increased temperature and rainfall events [3]. Installing Modis sensor on Terra spacecraft in 1999 paved the way for generation of snow cover maps [4]. Modis snow maps cover the whole ground on a daily basis and are presented with local resolution power of 500 meters. The algorithms used for creation of these maps use the spectrums reflected in bands 4 and 6 for production of Normal Difference Snow Index (NDSI) [5].

Snowmelt Runoff Modelling (SRM) was produced originally by Swiss researchers for management of water resources, irrigation and water supply. It is based on degree-day method. This model has been examined for simulation in 112 watershed basins in different points of the world by the Universal Organization of Climatology and has been specified as the most accurate model, with minimum level of errors, for snow melting simulation as compared to the other models.

Nagler et al. [6] predicted snowmelt runoff in Otztal basin in Australia using Modis optical satellite images and images of Envisat ASAR radar (in order to eliminate errors made in long cloudy days). Comparing snow maps obtained from SAR and optical images revealed systematic differences. In order to compensate for these differences, a semi-distributional model was used for approving satellite snow cover data usage in short-term runoff prediction. In this study, images of Aster and Modis were also compared. Results showed that Modis calculated and assessed more runoff in snow-free areas compared to in snowy areas.

Lee et al. [7] compared snow maps of Modis to maps prepared by National Operational Hydrologic Remote Sensing Center (NOHRSC) in upstream of Rio Grande basin and found out that both are influenced by cloudy conditions and the main error in both types of the maps is existence of the cloud. SRM model was used by Seidel and Martinec [8] in Swiss Alps so as to simulate snowmelt runoff, and snowmelt runoff was measured and predicted using images of Spot, Land sat, and NOAA for 13 sub-basins. SRM model worked well in simulation in all sub-basins. In addition, it was used successfully by Tekeli [9] in Euphrates basin for water years 1997 and 1998. Coefficient of determination and volume differences in these simulations varied between 0,85 ÷ 0,95 and 0,56 ÷ 9,3, respectively.

Najafi Igdir et al. [10] simulated snowmelt runoff using remote sensing and geographical information system (GIS) in Shahr-Chaee basin in Urmia. They extracted snow cover surface as the main needed hydrological variable using images of NOAA sensor of AVHRR satellite. Then SRM model was used for measuring snow runoff. They entered data and related parameters on a daily basis for 1996 ÷ 1997 into the model. In order to evaluate the model accuracy, observational and measured values were compared which showed successful and acceptable simulation in which coefficient of determination was 0,81 and volume difference was 2,75.

Najafi et al. [11] simulated snowmelt runoff in Mahabad basin using SRM model. Mahabad basin was divided into 4 height stories in order to achieve higher accuracy in computations. Input flow to dam was measured in two hydrometric stations before dam. Information of a thermometry station inside the Mahabad city and seven pluviometry stations and seven snow survey stations within basin were used. After applying inputs into model, simulation was carried out and simulated and measured hydrographs were drawn. Both hydrographs were compared and investigated in terms of consistency, regression and volume differences. Regression coefficient and volume difference were calculated as 0,85 and –3,79, respectively.

Porhemat et al. [12] used SRM model in Khersan sub-basin, which is one of Karun's head branches and lacks snow survey data and statistics. In addition, digital information of Avhrr sensor of NOAA satellite was used as time-series information source in snow cover area. In order to measure and evaluate the model, two water years 1996 ÷ 1997 and 1997 ÷ 1998 were selected and model's parameters were measured and determined based on observational data of daily discharges in 1996 ÷ 1997, and simulation accuracy of the model was evaluated in 1997 ÷ 1998. Evaluation of model in simulating snowmelt runoff and rain participation showed that daily discharge was measured by 88 % accuracy with coefficient of determination 0,774 and total flow volume was measured with 1,03 % difference compared to observational volume during the same period. Thus SRM model using satellite data works well in measurement of snowmelt runoff and in conditions of rain and snow participation in basins lacking statistics and it is recommended for such basins.

In addition, Abudu et al. [13] simulated and predicted snowmelt runoff in mountainous basins in northwest of China. Fatahi and Delavar [14], Dehghani and Majid [15] and Mir Yaghoobzadeh and Ghanbarpour [16] studied snowmelt runoff in mountainous basins in Iran using remote measurement in SRM model.

In this study, snowmelt runoff in Navrood basin is studied using satellite data for temperature and snow melt cover as input for SRM model as a new work, and data interaction was analyzed. Regarding vast amount of used satellite images, using MATLAB software for data analysis was considered as necessary. Using these data will help accurate prediction of water resources and confronting possible crises. The rest of the paper is structured as follows: Section 2 describes the materials and methods for case study; in Section 3, the results and discussion are presented; finally Section 4 includes conclusions of the present work.

2 Materials and Methods

2.1 The studied area

Navrood watershed basin at Asalem with an area of about 307 kilometers to the sea is located in the west of Guilan Province and in the limits of Talesh City (Fig. 1). Origin of the longest branches of Navrood River is initiated from eastern hillsides of Talesh Mountains and "Hejab", "Satle-khuni", "Asbe-rise", "Hafte-khuni", and "Boughrodagh" mountains, and goes on after joining other side branches of the river from east toward east.

It falls into Caspian Sea after passing through Asalem City and passing additional 4 km branches of Navrood River are used for irrigation of 2 000 hectares of rice fields, which is dominant cultivation in this area. Navrood watershed basin has currently two first class hydrometric stations, three first class evaporation survey stations, two ordinary pluviometer stations, 18 reserve pluviometer stations, and four snow survey stations. Kherjegil Hydrometric Station with the area of 266 square kilometers and average annual water of 157 million cubic meters is located at 6 kilometers above Asalem City from which statistical data are collected since 1965.

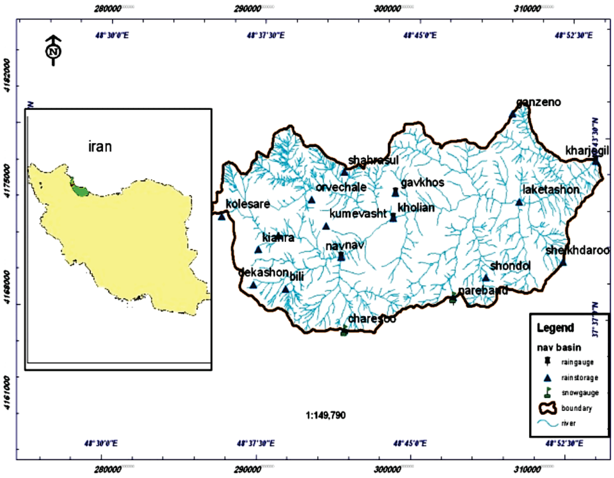

Figure1 Situation of hydro-climatologic stations of Navrood basin in the province and country

2.2 The data required for SRM model

The input data of snowmelt runoff simulation model (SRM) are separated into three groups as follows:

1) Specifications of the basin including the area of sub-basins, basin and height- area curve that in this study is obtained from topographic maps and DEM.
2) The parameters including C, runoff coefficient, grade-day factor, temperature gradient, critical temperature, the area common with rainfall and subsiding coefficient.
3) Variables including temperature and number of degree-day, amount of snowfall and snow cover surface. Snow surface temperature and day degree are also among Modis satellite data in thermal bands with local separation power of 1000 meters, which was changed to 500 meters.

2.3 The Used Ground Station Data

In order to enter other data used in the model, statistics and information of weather stations in basin and its surroundings were needed. To this end, Kherjegil Station, Khalian Station and Synoptic Station of Khalkhal were used. The used data includes the daily data of snowfall, average temperature and runoff. In addition, for determination of snow coefficient, the data of snow survey stations in highlands of Navrood Basin and Arpachay Basin were used. Tab. 1 gives general characteristics of weather stations used in this study.

Table 1 General characteristics of weather stations (Gilan Regional Water Company)

No	Station	Station Type	Longitude	Latitude	Height / m
1	Kherjegil	Evaporation survey station	48°53'44"	37°42'43"	140
2	Kholian	Evaporation survey station	48°43'56"	37°40'27"	780
3	Nav	Evaporation survey station	48°41'15"	37°39'00"	1000
4	Gavkhas	Evaporation survey station	48°44'00"	37°41'00"	1300
5	Khalkhal	Synoptic	48°31'00"	37°38'00"	1796
6	Arpachay	Snow survey	48°32'01"	37°51'44"	2440
7	Almas ghat	Snow survey	48°40'28"	37°35'24"	2216
8	Larzane	Snow survey	48°43'41"	37°36'17"	1977
9	Nareband	Snow survey	48°46'54"	37°37'42"	1798
10	Cherasudagh	Snow survey	48°41'41"	37°36'24"	2066

2.4 Methodology (extraction of snow cover surface data and temperature from MODIS products)

For extraction of snow cover surface data and ground surface temperature, first satellite data daily and in an 8-day period, A2 snow surface, MOD10A1 and ground surface temperature A2 and MOD11A1 with HDF format were retrieved from WIST site. These images are related to sheet H21V05 from WIST site. Then images were imported into Erdas Imagine software and they were converted into TIF format. Ground reference operations were then performed. Finally watershed basin limits are cut from the images.

After the above-mentioned steps, all images were recalled by the programs provided in MATLAB programming environment and snow surface and ground surface temperature were extracted for the whole basin, two sub-basins and the studied height stories. Due to the fact that temperature images are with local separation power 1000 meters, they were converted into local separation power of 500 meters so that all images have the same local separation power.

All data in time period of Oct. 16th until Apr. 24th of the water year were received. The reason for selecting this time period was initiation and termination snowfall in this 9-year period. Then graphs of snow cover surface and ground surface temperature were drawn in Excel software environment using extracted data. These graphs were prepared for better investigation and understanding of data status in basin surface and their interaction.

After determining snow cover amount and earth surface temperature from 432 Modis satellite images in 6 height regions with 500 m distance these data was entered into model so that snowmelt runoff in height levels is calculated and model accuracy is increased. In addition, in these levels input parameters including rain and snowmelt runoff coefficient, degree-day factor, critical temperature, remission rate, time delay and precipitation, physical and empirical relationships and correlations were estimated and entered into the model.

3 Results and Discussion

3.1 Investigation of the Snow Surface and Temperature Changes Regime in the Basin

Investigation of extreme ups and downs in graphs (Fig. 2) all repeated in different years in time period of 2000 ÷ 2009 implies that snow cover surface is affected considerably by other climatic factors such as temperature, wind, and precipitations in this basin. Increase in snowfalls, especially in appropriate temperature condition, leads to increased snow cover surface in the basin and its durability, and its sever decrease is also affected by extreme temperature changes and hot winds which happening during these months causes temperature rise between 10 to 15 degrees in the respective time period.

These changes have had their effect on river's water release trend, and it is subjected to periodic ups and downs, which may also affect model simulation and reduce correlation between measured and simulated data of water release.

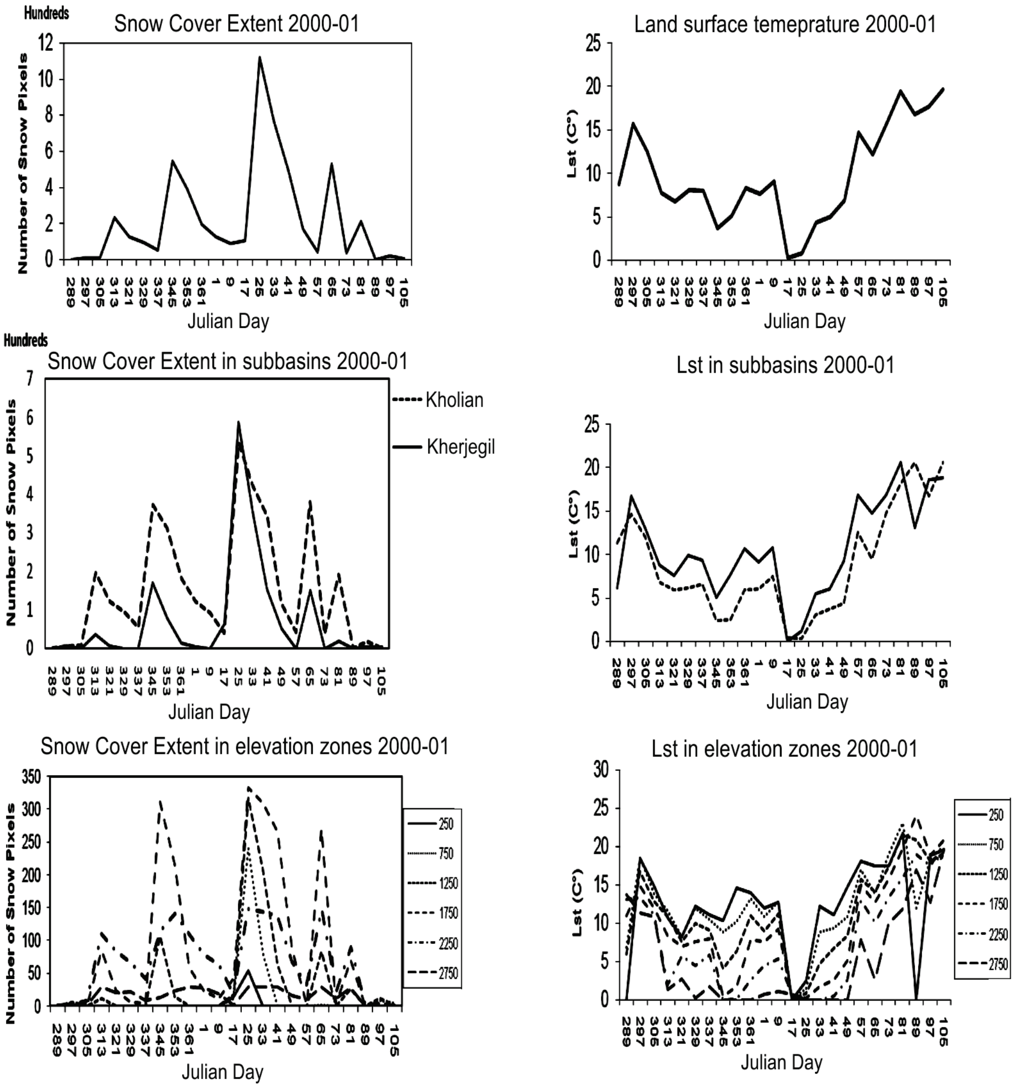

Figure 2 Graphs of snow cover surface and temperature changes regime in terms of basin, sub-basin and height stories (water year of 2000 ÷ 2001)

3.2 Investigation of changes between the extracted and measured data

The graph of synchronous changes in data of snow cover surface and ground surface temperature with 8-day time steps in time period of Oct. 16th until Apr. 24th in water year of 2000 ÷ 2001 (Fig. 3) shows interaction of two groups of data well. Increase of temperature in above zero degrees centigrade (snow melting point in the basin) always caused snow surface decrease in the basin and on the contrary decrease of temperature in below zero degree centigrade increased snow surface.

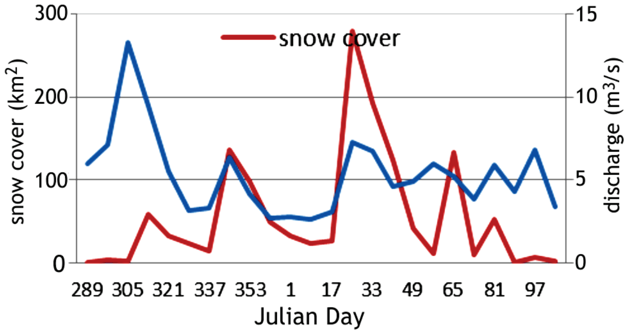

Figure 3 Synchronous changes in snow cover surface and ground surface temperature data (2000 ÷ 2001)

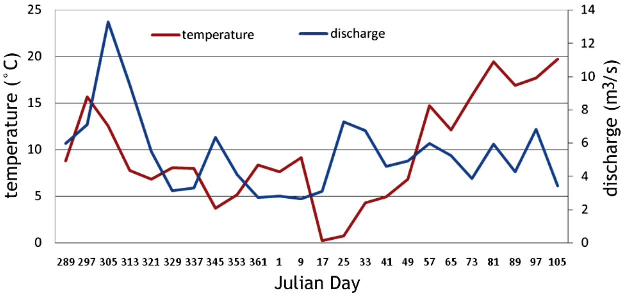

Figure 4 Synchronous changes in snow cover surface and discharge data (2000 ÷ 2001)

Considerable influence of temperature parameter in snow cover surface justifies ascending and descending trend in graphs well. Sever changes in direction and slope of graphs result from direct effect of temperature. Hot wind in year's cold seasons plays a noticeable role in such a way that basin's snow reserve is decreased to zero.

Another investigation was performed between snow cover surface data and water release observations data in the same period. As shown in Fig. 4, snow surface decrease accompanies increase in the river's water release, though share of precipitations in increase of water release in the river is noticeable. Regarding performed calculations and estimation of 12 % share of snowmelt runoff in total flow volume, snowmelt role in water release level is evident.

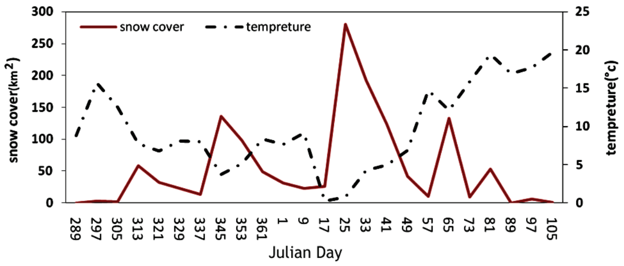

Figure 5 Synchronous changes in ground surface temperature and discharge (2000 ÷ 2001)

In Fig. 5, surface temperature changes obtained from the satellite data were compared to the observed water release data in Kherjegil Station in Navrood Watershed Basin. Surface temperature changes with amount of water release follow the same pattern expectation for a few days, consequently it can be concluded that increased temperature is accompanied by increased snow melting and therefore increased water release.

3.3 SRM model execution

For calibration of the model and evaluation of simulation accuracy, water release data during the years 2000 ÷ 2001 in Kherjegil Hydrometric Station located at Navrood Watershed Basin output point in time period from Oct. 16th until Apr. 24th was used. Among needed data, snow runoff coefficient is information, for calculation of which density measured value and measured snow water equivalent value was used in snow survey stations in Navrood and its surrounding basins given in Tab. 1. Model output is given in Tab. 2 and Fig. 6.

For specifying accuracy of SRM model, a qualitative model, observation of hydrographs match and two quantitative criteria including Coefficient of Determination (R2) and volume difference (DV) are used. In addition root mean square error (RMSE) criterion was used for comparing measured and simulated data statistically, the value of which is given in Tab. 2 and Fig. 6.

Table 2 Results of snowmelt runoff simulation in Navrood Watershed Basin, Kherjegil Station

Index	Result
Measured runoff volume (mm^3)	86,80
Measured runoff average (m^3/s)	5,23
Computed runoff volume (mm^3)	84,70
Computed runoff average (m^3/s)	5,11
Volume difference (%)	2,40
Coefficient of determination (%)	28
Root mean square error (RMSE) (%)	2,90

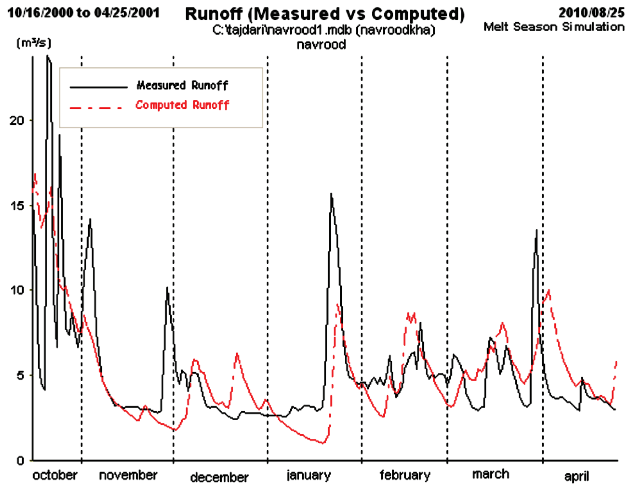

Figure 6 Simulation graph of snowmelt runoff in Navrood Watershed Basin, Kherjegil Station (black graph shows measured runoff and discrete red graph shows computed Runoff)

4 Conclusion

Determination of the share of snowmelt runoff in Navrood Watershed Basin was investigated in this research. This research has two basic features that distinguish it from the other studies on this ground. One is using the applications of MATLAB software in extraction of the required data of the model from 432 satellite images of snow cover and ground surface temperature in such a way that working with this amount of images would be difficult and time-consuming without using this software. And the other is application of the model in this basin with abundant and continual floodwaters during the year and therefore intense changes in annual flow curve, which makes this simulation difficult.

Some of the results obtained from this study are given in the following:

1) Estimated error of discharge and volume increases in rainfall (flood) conditions compared to the no rainfall (non-flood) conditions. This error can be observed in graphs of measured and simulated results in graph 6 arising from the model output.

2) The data given in Tab. 1 calculates the volume difference error in the limit of 2,4 % which is the result of the good estimation of snowmelt runoff by the model.
3) In mountainous areas satellite images enjoy high efficiency for determination of coverage surface and snow map.
4) Low estimation of runoff by the model in October and November as compared to the runoffs measured in the mentioned months shows increase of temperature in the basin surface and therefore evaporation and perspiration.

Share of snowmelt runoff in the total volume is estimated to be 12 %.

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