Application of the SRM Snowmelt Runoff Model in the Xilin River Basin (Postprint)

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Abstract

To verify the applicability of the SRM (Snowmelt-Runoff Model) in cold and arid grassland watersheds, this study—based on an elaboration of model structure and parameter significance—combined MODIS snow cover data with observed meteorological and hydrological data from the snowmelt period (March–May) of 2014–2016 in the upper reaches of the Xilin River basin. Employing WinSRM version 1.10, runoff during the snowmelt period was simulated for the years 2014–2016. The results demonstrate that the SRM model can satisfactorily reflect the runoff variation trend during the snowmelt period in the Xilin River, effectively capturing both the arrival date and peak flow of snowmelt runoff floods. Model accuracy evaluation reveals that the coefficient of determination (R^2) and volume difference (DV) for the three-year simulated values both exceed the mean model simulation accuracy published by the World Meteorological Organization. Consequently, the SRM snowmelt-runoff model exhibits favorable applicability in the upper Xilin River basin, which holds significant importance for the rational utilization of grassland ice-snow water resources.

Full Text

Application of a Snowmelt Runoff Model in the Xilin River Basin

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Abstract

In this study, MODIS snow cover data and measured meteorological and hydrological data from the upper reaches of the Xilin River Basin during the snowmelt period (March to May) of 2014–2016 were simulated using WinSRM 1.10. The purposes were to verify the applicability of a snowmelt runoff model (SRM) in drainage basins in arid and alpine steppe regions based on description of the model structure and parameter meanings, and to reveal the proportion of spring snowmelt volume in annual runoff volume in the upper reaches of the Xilin River Basin from 2014 to 2016. The results showed that the SRM could ideally reflect the change trend of spring snowmelt volume in the study area and predict the timing of spring snowmelt flood peaks. The accuracy of the model was evaluated, and the goodness-of-fit coefficient (R^2) and volume difference (DV) of the 3-year simulated values were obtained, which were superior to the mean values published by the World Meteorological Organization. Therefore, the SRM has good applicability in the upper reaches of the Xilin River Basin and is of great significance for the rational use of ice-snow resources in grasslands.

Keywords: snowmelt runoff model; snowmelt runoff; model variables; model parameters; model applicability; Xilin River Basin; Inner Mongolia

1 Study Area

The Xilin River Basin is located in Inner Mongolia Autonomous Region, spanning latitudes 43°26 –44°39 N and longitudes 115°32 –117°12 E, with a total area of 10,542 km². The upper reaches of the basin, covering 3,852 km², were selected as the study area. This region features an alpine steppe climate with an average annual temperature of -6 to -7.32°C and annual precipitation ranging from 250 to 400 mm. Snowmelt runoff constitutes approximately 19.8% of the annual runoff volume, playing a crucial role in water resource availability. The snowmelt period typically occurs from March to May, with snow cover depletion significantly influencing river discharge during spring months.

2 Data and Methods

2.1 Data Sources

MODIS snow cover products including MOD10A1, MOD10A2, MOD10C1, MOD10C2, and MOD10L2G were obtained from the National Snow and Ice Data Center (NSIDC) at 500 m spatial resolution and 8-day temporal resolution. Meteorological data comprising temperature and precipitation were acquired from the China Meteorological Administration. Hydrological runoff data from 1963–2013 were used for model calibration and validation, with 2007–2013 serving as the calibration period and 2014–2016 as the validation period.

2.2 SRM Model Structure

The Snowmelt-Runoff Model (SRM) was originally developed by Martinec in 1975 and computes daily runoff based on snowmelt and rainfall contributions. The model structure is described by the following equation:

$$Q_{n+1} = [CS_n \cdot \alpha_n (T_n + \Delta T_n) S_n + CR_n P_n] \cdot A \cdot 10000(1 - K_{n+1}) + Q_n K_{n+1}$$

where: - Q is runoff $(m^3 \cdot s^{-1})$ - CS is the snowmelt runoff coefficient - α is the degree-day factor $(cm \cdot °C^{-1} \cdot d^{-1})$ - T is temperature (°C) - ΔT is the temperature lapse rate adjustment - S is snow cover extent - CR is the rainfall runoff coefficient - P is precipitation (mm) - A is basin area - K is the recession coefficient - n is the day index

2.3 Model Parameters

Temperature Data: Daily maximum and minimum temperatures were interpolated using the lapse rate formula:

$$T = \frac{T_{min} + T_{max}}{2}$$

The temperature lapse rate was set at -0.65°C per 100 m elevation increase. Temperature data were corrected for elevation differences between meteorological stations and the basin.

Snow Cover Data: MOD10A2 8-day composite snow cover products were used to derive daily snow cover extent through linear interpolation. Snow depletion curves were established for each elevation zone.

Depletion Curve Parameters: The recession coefficient K was calculated using the relationship:

$$K_{n+1} = xQ - y$$

where x and y are parameters derived from observed hydrograph recession analysis. Based on 2007–2013 data, the optimized parameters were $x = 1.020278$ and $y = 0.0087$.

Degree-Day Factor: The degree-day factor α was determined based on land cover type and snow characteristics, with values ranging from 0.35 to 0.60 cm · °C ¹ · d ¹ for different elevation zones.

3 Results

[Figure 1: see original paper] shows the location of the upper Xilin River Basin and distribution of observation stations. [Figure 2: see original paper] illustrates the proportion of spring snowmelt volume in annual runoff during 1963–2013, indicating significant interannual variability.

[Figure 3: see original paper] presents the change trends of snow coverage and snowmelt duration (March–May) in the upper Xilin River Basin during 2014–2016. Snow cover typically peaked in early March and depleted by late May, with considerable year-to-year variation in depletion rates.

The model performance was evaluated using the coefficient of determination (R^2) and volume difference (DV):

$$R^2 = 1 - \frac{\sum(Q_{obs} - Q_{sim})^2}{\sum(Q_{obs} - \bar{Q}_{obs})^2}$$

$$DV = \frac{V_R - V'}{V'} \times 100\%$$

where V_R is simulated runoff volume and V' is observed runoff volume.

[Figure 4: see original paper] shows the scatter diagram of the depletion process during the snowmelt period for 2007–2013, demonstrating good agreement between simulated and observed values. [Figure 5: see original paper] compares measured and simulated runoff volumes for 2014–2016.

presents the model evaluation metrics for the three validation years. The 3-year average R^2 was 0.8487, 0.8856, and 0.8165 respectively, with volume differences of 5.5452%, 3.1859%, and 1.7070%. These results exceed the performance criteria established by the World Meteorological Organization for snowmelt runoff models.

4 Discussion

The SRM demonstrated strong capability in simulating snowmelt runoff processes in the upper Xilin River Basin. The model accurately captured the timing and magnitude of spring flood peaks, which is critical for water resource management in this grassland region. The high R^2 values and low DV percentages indicate that the parameter calibration was successful and that the model is suitable for operational forecasting.

Key factors contributing to the model' s performance include: (1) the use of high-resolution MODIS snow cover data that accurately represented snowpack dynamics, (2) proper accounting for elevation effects through temperature lapse rate corrections, and (3) robust calibration of the degree-day factor and recession coefficients using long-term observational data.

The results have important implications for managing water resources in the Xilin River Basin, particularly for agricultural irrigation and ecological conservation in the grassland ecosystems. The model can support decision-making regarding water allocation during the critical spring snowmelt period.

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Note: Figure translations are in progress. See original paper for figures.