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Study on snowmelt runoff simulation in the Kaidu River basin

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Alpine snowmelt is an important generation mode for runoff in the source region of the Tarim River basin, which covers four subbasins characterized by large area, sparse gauge stations, mixed runoff supplied by snowmelt and rainfall, and remarkably spatially heterogeneous precipitation. Taking the Kaidu River basin as a research area, this study analyzes the influence of these characteristics on the variables and parameters of the Snow Runoff Model and discusses the corresponding determination strategy to improve the accuracy of snowmelt simulation and forecast. The results show that: (i) The temperature controls the overall tendency of simulated runoff and is dominant to simulation accuracy, as the measured daily mean temperature cannot represent the average level of the same elevation in the basin and that directly inputting it to model leads to inaccurate simulations. Based on the analysis of remote sensing snow maps and simulation results, it is reasonable to approximate the mean temperature with 0.5 time daily maximum temperature. (ii) For the conflict between the limited gauge station and remarkably spatial heterogeneity of rainfall, it is not realistic to compute rainfall for each elevation zone. After the measured rainfall is multiplied by a proper coefficient and adjusted with runoff coefficient for rainfall, the measured rainfall data can satisfy the model demands. (iii) Adjusting time lag according to the variation of snowmelt and rainfall position can improve the simulation precision of the flood peak process. (iv) Along with temperature, the rainfall increases but cannot be completely monitored by limited gauge stations, which results in precision deterioration.

snowmelt runoff model (SRM), Kaidu River basin, runoff simulation, runoff coefficient for rainfall, time lag

In the arid area of northwest China, both the snow accumulation and snowmelt play an important role in regional water resource and environment. Alpine snowmelt is the major source of many rivers and significantly contributes to the local populace and social-economic development. But when snowmelt and storms combine, the area is also easily flooded. Exploring the snowmelt rule, simulating runoff processes and forecasting runoff changes in future climates at the basin scale are significant for generating a water utility plan, the sustainable development of animal husbandry and the economy, and flood prevention.

The Snowmelt-Runoff Model (SRM) is designed to simulate and forecast daily snowmelt flow in mountain basins. After it was initially developed by Martinec and Rango in the early 1980s, the SRM has been successfully applied to over 80 basins in 25 countries in northern America, western Europe and southern Asia[1]. Though the climate conditions of these regions are much different from those of the arid areas of northwest China, the model performance in arid areas is also satisfying[2−4].

The SRM is a relatively simple degree-day model,

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which uses daily temperatures, precipitation and snow cover as basic input variables. For the model parameters can be determined from physical environment, such as geography, climate and hydrology, not through fitting and calibration, it is appropriate for climate change analysis[5, 6]. The SRM is categorized as a deterministic, conceptual, distributed, and physically based model by the World Meteorological Organization[7]. With the rapid development of remote sensing snow monitor technology in recent years, the precision of snow data has been great improved, satisfying the requirement of the SRM for snow cover[8]. The model computes the temperature and precipitation by extrapolating the measured data to the mean hypsometric altitudes of the respective elevation zones by altitude gradients. Thus, it is necessary that the measured data should be representative of the altitude. As in earlier research work, the measured data can be directly used by the model when the gauge stations are sufficient or the basin area is very small[9−11].

The four subbasins of the Tarim River basin have the following four characteristics: (i) Snowmelt and precipitation simultaneously supply the river every year at a certain period. (ii) The subbasins cover a large area with complex terrain and remarkably spatially heterogeneous precipitation. (iii) The meteorological station is scarce and located at the low mountainous area in the basin. (iv) The meteorological condition in the basin is usually influenced by exterior climate[12]. For snowmelt and rainfall to simultaneously supply stream, reasonable temperature and precipitation are equally important, but the geographic characteristics and condition of the gauge stations make the collected data less representative, so it is crucial for simulation accuracy to obtain valid model input. Similarly, whether these kinds of basin characteristics influence the model parameter selection remains unknown and need further research. The snowmelt period of the Kaidu River basin concentrates in the months of April and May, and the supply proportion of rainfall to runoff increases after May. Only two meteorological stations provide data in the basin with complex terrain. Relative to three other subbasins, the Kaidu River basin is more sealed and less influenced by exterior climate. Taking Kaidu basin as a representative basin, this study discusses the impact of basin characteristic on the determination of model inputs (temperature and precipitation) and parameters (runoff coefficient for rainfall and lag time) and proposes an improvement strategy whose necessity and rationality are verified through contrasting different setting schemes of variables and parameters.

1 Study area

The Kaidu River basin is located in the north margin of the Yanqi basin, Xinjiang Uygur Autonomous Region, and is enclosed between latitudes 42°14′N－43°21′N and longitudes 82°58′E－86°05′E (Figure 1). The Kaidu River originates from the Hargat valley and the Jacsta valley on the Sarming Mountain with a maximum altitude 5000 m, located in the middle of Tianshan Mountain. The mainstream traverses through Small-Urdus basin to Bayanbulak hydrological station from east to west, then turns towards southeast and passes through the Husitaixili, the Big-Urdus basin and along a canyon, finally arrives at the Dashankou station. The basin covers about 1.9×10^4 km^2 and has a mean elevation of 3100 m above the basin outlet. The abundant water of the Kaidu River assures the social-economic development and the ecological-environmental construction of the Mongolian Autonomous Prefecture of Bayingulin. Additionally, the spring snowmelt water is also the main water source for the germination of the Bayanbulak pasture. The snow accumulation lasts from November of every year to March of the next year. With temperatures increasing during April and May, seasonal snowmelt water begins supplying the river and usually leads to flooding, and the precipitation begins supplying the river in early summer. There are only two gauge stations in the basin, one is the Bayanbulak station which records temperature and precipitation data, the other is the Dashankou station which provides runoff and precipitation data. As the physical environment varies drastically with increasing altitudes, the basin with a great elevation range was divided into several zones to better describe the physical environment. Former studies suggest that an interval less than 500 m is better for the elevation zones, while excessively small intervals will increase the modeling complexity. Based on a 1:250000 scale DEM data, the Kaidu River basin is divided into 8 elevation zones (Table 1).

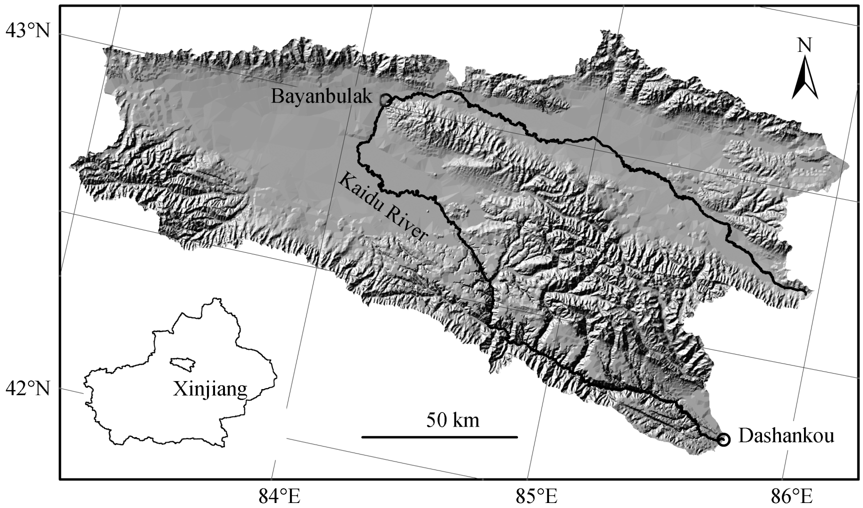

Figure 1 The Kaidu River basin.

Table 1 Elevation zones of the Kaidu River basin

Zone	Elevation range(m)	Area (km^2)	Area percent (%)	Mean elevation (m)
A	1400—1825	198.63	1.1	1670.97
B	1825—2250	241.87	1.3	2045.93
C	2250—2675	5297.16	28.3	2512.73
D	2675—3100	5696.69	30.4	2857.80
E	3100—3525	4193.95	22.4	3293.17
F	3525—3950	2454.75	13.1	3689.58
G	3950—4375	619.37	3.3	4056.95
H	4375—4800	22.60	0.1	4424.44
Whole basin	1400—4800	18725.02	100	2924.81

2 Determination of variables and parameters of SRM

2.1 Introduction of SRM

The SRM calculates the daily runoff by computing the water produced from snowmelt and rainfall on all elevation zones and adding them to the recession flow according to the following equation:

$$Q_{n+1} = \sum_{i=1}^{m} [C_{Sn} \cdot a_n (T_n + \Delta T_n) S_n + C_{Rn} P_n] \frac{A_i \cdot 10000}{86400} \cdot (1 - k_{n+1}) + Q_n k_{n+1}, \quad (1)$$

where Q($m^3 \cdot s^{-1}$) is the average daily discharge, C is the runoff coefficient expressing the losses as a ratio (runoff/precipitation), with C_S referring to snowmelt and C_R to rain, a_n (cm · ℃$^{-1}$ · d^{-1}) is the degree-day factor indicating the snowmelt depth resulting from 1 degree-day, T_n(℃ · d) is the number of degree-days above the base of 0℃, ΔT_n(℃ · d) is the adjustment by temperature lapse rate for different altitudes of meteorological stations, S_n is the ratio of the snow covered area to the total area, P_n (cm) is the precipitation contributing to runoff, A_i (km^2) is the area of the basin or zone, k_n is the recession coefficient indicating the decline of discharge in a period without snowmelt or rainfall, n is the sequence of days during the discharge computation period, 10000/86400 converts cm · km^2 · d^{-1} to m^3 · s^{-1}, m is the number of elevation zones. T, S and P are variables, others are parameters.

Except T, P, C_R and time lag (L), other variables and parameters are determined according to the model manual[1]. Snow coverage is obtained from the snow coverage depletion curve. For the cloud shading will seriously decrease the accuracy of snow coverage data, the snowmelt season (April 6—May 25) of 1993 with little cloud is selected as study period. The depletion curve of snow coverage is obtained through the following approaches[13]: (i) Based on NOAA/AVHRR data, snow and cloud are extracted through the theta method, which was developed by NOHRSC and is used to discriminate the snow, cloud and water on remote sensing data through establishing three- and four-dimension space with different channel combinations. After extrapolating the snow coverage under clouds with long sequence images, a ten-day period snow coverage map is obtained. (ii) The percent of snow coverage is calculated by overlaying the snow coverage map on the DEM. (iii) The depletion curve of snow coverage is obtained by linearly interpolating the ten-day period snow coverage to daily snow coverage (Figure 2).

For lack of actual material, most model parameters were determined by adjusting parameters used in other study areas based on the comparison of physical environment (Table 2). Through the analysis of hydrological sequences in 1993, two constants relevant to k are calculated: $x = 0.998$, $y = 0.03$.

2.2 Estimation of temperature

Temperature is an important variable in the SRM, and the accurate average temperature at the reference latitude is fundamental for guaranteeing simulation precision, especially for large basins[14]. The SRM accepts either the daily mean temperature (T_{avg}) or the average of the daily maximum temperature (T_{max}) and the daily minimum temperature (T_{min}), while using measured data directly is generally unreasonable. Swamy[10] calculated several values for T_{avg} through various combinations of hourly observed data, and the simulation study indicated that using the average of measured T_{max} and T_{min} led to a decrease in accuracy during some periods. In order to obtain the representative basin mean temperature, Richard et al.[9] attempted different weighting methods for data collected from several stations and showed that different temperature inputs may cause a large difference[9].

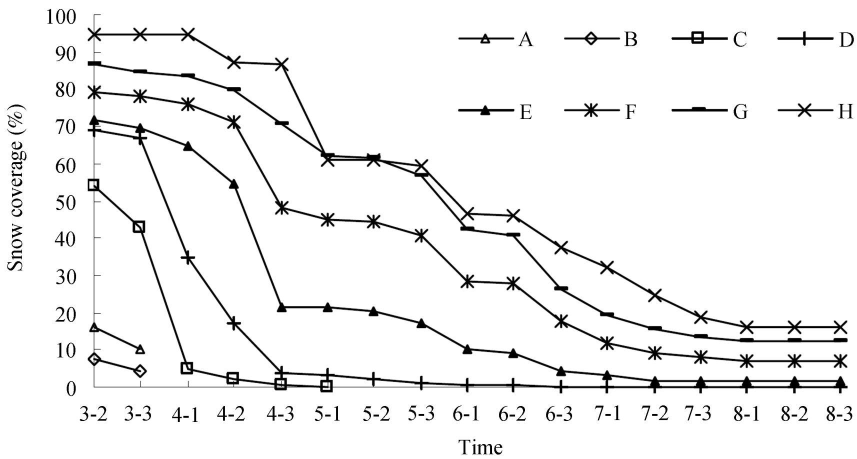

Figure 2 Snow coverage depletion curve for the Kaidu River basin in 1993 (see Table 1 for A—H). 3–2 means the second ten days of March; 3–3, the third ten days of March; 4–1, the first ten days of April; ⋯; 8–3, the third ten days of August.

Table 2 The parameters of the SRM for the Kaidu River basin during the snowmelt period in 1993

Zone (m)	Period	a (cm・(℃・d)$^{-1}$)	C_s	γ	T_{CRIT} (℃)	Rainfall contributing area
C(2250－2675)	Apr 6－Apr 20	0.35	0.6	0.45	2.5	0
	Apr 21－May 25	0.4	0.5	0.45	2.5	1
D(2675－3100)	Apr 6－Apr 20	0.3	0.65	0.45	2.5	0
	Apr 21－May 25	0.35	0.55	0.45	2.5	1
E(3100－3525)	Apr 6－Apr 20	0.25	0.65	0.65	3	0
	Apr 21－May 25	0.3	0.55	0.65	3	1
F(3525－3950)	Apr 6－Apr 20	0.25	0.7	0.65	3	0
	Apr 21－May 25	0.25	0.65	0.65	3	0
G(3950－4375)	Apr 6－Apr 20	0.25	0.75	0.65	3	0
	Apr 21－May 25	0.25	0.75	0.65	3	0
H(4375－4800)	Apr 6－Apr 20	0.25	0.75	0.65	3	0
	Apr 21－May 25	0.25	0.75	0.65	3	0

According to the measured data, T_{avg} was below 0℃ during the first ten days of April at the Bayanbulak station (2458 m), which is under the hypsometric mean elevation of zone C (2512 m), suggesting that the T_{avg} of zone C extrapolated using lapse rate must be below 0℃ and snowmelt water calculated by the SRM is zero. But according to remote sensing snow cover map, the snow cover area reduced 38% during the first ten days of April. This indicates that the measured temperature at the Bayanbulak station is lower than the basin's average temperature at the same elevation. The topography shows that zone C is mostly located in an open flat area and the Bayanbulak station at the narrow passage between two mountains. Because of the shelter of the two mountains, the Bayanbulak station accepts less solar radiation than other positions which causes somewhat lower temperature. For T_{max} is above 0℃ from April 6 and had a better uniformity with the snowmelt process, $T_{max}\times\alpha$ ($0.1\leqslant\alpha\leqslant1$) is put into the SRM to carry out the experiments, and α is determined based on the simulation results, which also are compared with the result using T_{avg}.

2.3 Estimation of precipitation and C_R

The calculation of rainfall supply to runoff is dependent upon precipitation and the C_R assigned to all elevation zones in the SRM, with the latter reflecting the evaporation loss. Reviewing the model structure, it can be found that the model does not have a similar component, rainfall coverage percent, for rainfall runoff as snow coverage percent for snowmelt runoff. Thus, the precipitation entered should be the mean areal precipitation (MAP) of each elevation zone. Usually, the measured precipitation is directly used in the SRM, which is valid for moderate and small basins in arid areas or large basins of humid areas and will not result in serious errors. The C_R for rainfall events is set according to its physical meaning and is generally slightly less than or equal to C_S generally ($C_R = C_S$).

There are two problems with the precipitation in Kaidu basin. The first is that only two low altitude precipitation stations are available (zones A—C) and the second is the remarkably spatially heterogeneity of the precipitation. The precipitation of high altitude zones is usually extrapolated through altitude gradients. However, the spatial heterogeneity of precipitation impedes its coverage area to be determined, which makes it impossible to compute the MAP over each elevation zone. Another disadvantage is that with the temporal and spatial variations of the altitude gradient, it is unrealistic to calculate the MAP over each zone. Therefore, it is nonsensical to set precipitation and C_R for elevation zones, which just increases the modeling difficulty and does not improve accuracy.

Based on the analysis of measured data at some short-term gauge stations during the 1980s, the respective cover areas of the two long-term stations can be simply determined: the Dashankou station located in zone A controls the canyon area of the middle reach of the basin, including zones A, B and few portions of other zones; the Bayanbulak station located in zone C controls major parts of zones C—H. The application sets parameters according to control range, other than elevation zone: the precipitation of zones A—B and zone C are assigned with the β times measured precipitation at the Dashankou and Bayanbulak stations ($\beta\cdot P$, $\beta>1$), respectively, and that of zones D—H with zero. The $\beta\cdot P$ is the MAP over the control range of each station. Obviously, the precipitation input is still impossible to be equal to the actual precipitation with any β, thus, the correct net supply water cannot be obtained using physical C_R. If the physical meaning of C_R is ignored, only regarding it as a correctional coefficient for water loss and supply, and determining its rule, the precipitation input can be better obtained with β and C_R. The following parts attempt to determine the rule of β and C_R, and verify this tentative plan.

2.4 Estimation of L

The time lag (L) reflects the extent that the outflow lags behind the generation of supply water, determines the daily allocation of water supply and does not explicitly appear in eq. (1). The characteristic daily fluctuations of snowmelt runoff enable the time lag to be determined through direct comparison between temperature sequences and hydrographs. The premise of using the constant L during the entire snowmelt season is that the runoff is only supplied by snowmelt water and the confluence time variation caused by position variation of water generation is negligible. But in regard to large-scale basins in arid areas, as it begins raining at lower elevation regions, higher elevation regions still keep snowmelt, thus the runoff is supplied by both rainfall and snowmelt. On the other hand, the change of water generation position is much more remarkable.

Comparing the temperature sequence measured at the Bayanbulak station and the discharge sequence at the Dashankou station during the snowmelt season, the time lag has no obvious pattern except in approximately two days (L=36 h) in the initial stage. This indicates that the time lag is not determined by snowmelt only. Obviously, the distance between water generation positions and the basin outlet directly influences the time lag, which are presented as a positive correlation. The water generation position includes snowmelt position and rainfall position. For snowmelt, not only the change of elevation zones, but also the position variation in the identical elevation zone will influence the time lag. For example, according to the snowmelt map in the first and second ten days of April (Figure 3, obtained through subtraction between two neighboring snow coverage maps), the snowmelt in the first ten days mainly takes place at the position far from the basin outlet on C—D elevation zones, while the snowmelt in the second ten days is mainly at the position on D elevation zones near the basin outlet. Theoretically, the time lag for the second ten days should be smaller than that for the first ten days. For rainfall, the rainfall events have an obvious difference in time, frequency and quantity between the Bayanbulak and Dashankou stations, so its position must be considered when discussing the impact of a rainfall event on the time lag. Clearly, the outlet discharge responds to the rainfall events measured at the Dashankou station more quickly than that at the Bayanbulak station, thus, the time lag will be smaller when rainfall events take place in the control range of the Dashankou station. Here we present qualitative analysis, and the concrete value will be determined through adjustment in the simulation process.

3 Snowmelt runoff simulation and analysis

3.1 Accuracy criteria

Two accuracy criteria, R^2 and D_V, are adopted to evaluate the simulation result. They are defined as

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(Q_i - Q_i')^2}{\sum_{i=1}^{n}(Q_i - \bar{Q})^2}, \tag{2}$$

where R^2 is a measure of model efficiency, Q_i is measured daily discharge, Q_i' is simulated daily discharge, $\bar{Q}$ is average daily discharge for the simulation year or simulation season, n is number of daily discharge values. D_V (%) is the percentage difference between the total measured and simulated runoff.

$$D_V = \frac{V_R - V_R'}{V_R} \cdot 100, \tag{3}$$

V_R is measured runoff volume, V_R' is simulated runoff volume. The closer R^2 to 1 and D_V to 0, the more precise the simulation will be.

3.2 Snowmelt runoff simulation

Based on the above analysis, 36 different modeling attempts with different combinations of variables and parameters are performed over the Kaidu River basin for the 1993 snowmelt season (Table 3). A1 and A2 represent adjusted C_R and L according to the above rule (Figure 4).

It is obvious that the temperature selection plays the decisive role in determining the simulation accuracy, which cannot be effectively improved by adjustment of the other three parameters when the temperature is unreasonable. The snowmelt is overestimated using $T_{\max}$ which leads to more runoff than measured runoff, and is underestimated using T_{avg} for it is below 0℃ and massive snowmelt water is not to be computed, which led to less runoff than actual runoff (Figure 5 (a)). The simulation tests indicate that the 0.5 time measured T_{avg} can better represent the average temperature at the same latitude of the basin and can greatly improve the simulation accuracy (Figure 5 (b)).

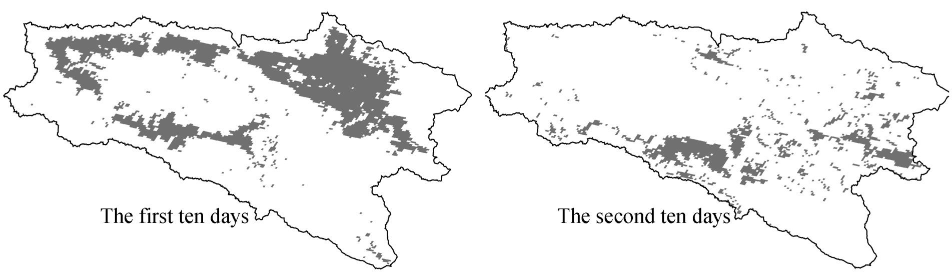

Figure 3 The snowmelt map of the first ten days and the second ten days of April.

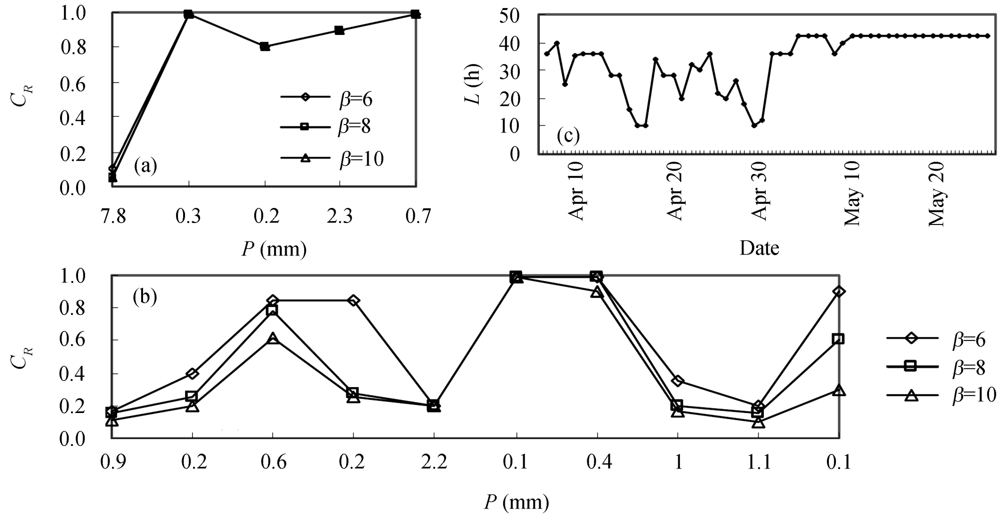

Figure 4 The sequence of C_R and L. (a) C_R for the Dashankou station; (b) C_R for the Bayanbulak station; (c) L series for snowmelt season.

Table 3 Evaluation of impact of different combinations of variables and parameters on snowmelt runoff simulation

Scheme	Variables and parameters			R^2	D_v (%)	Scheme	Variables and parameters			R^2	D_v (%)
	P	C_R	L (h)				P	C_R	L (h)		
					$T = T_{avg}$						
1	$\beta = 6$	C_R=C_S	36	–0.67	54.77	7	$\beta = 6$	C_R=C_S	A2	–0.64	55.05
2	$\beta = 8$	C_R=C_S	36	–0.18	44.47	8	$\beta = 8$	C_R=C_S	A2	–0.13	44.78
3	$\beta = 10$	C_R=C_S	36	0.23	30.83	9	$\beta = 10$	C_R=C_S	A2	0.28	31.35
4	$\beta = 6$	A1	36	–0.68	52.76	10	$\beta = 6$	A1	A2	–0.63	53.22
5	$\beta = 8$	A1	36	–0.49	45.88	11	$\beta = 8$	A1	A2	–0.41	46.58
6	$\beta = 10$	A1	36	–0.34	37.96	12	$\beta = 10$	A1	A2	–0.24	39.07
					$T = T_{max}$						
13	$\beta = 6$	C_R=C_S	36	–39.68	–252.7	19	$\beta = 6$	C_R=C_S	A2	–39.76	–251.0
14	$\beta = 8$	C_R=C_S	36	–44.11	–268.5	20	$\beta = 8$	C_R=C_S	A2	–44.3	–266.9
15	$\beta = 10$	C_R=C_S	36	–48.83	–284.2	21	$\beta = 10$	C_R=C_S	A2	–49.1	–282.6
16	$\beta = 6$	A1	36	–37.27	–244.9	22	$\beta = 6$	A1	A2	–37.36	–243.2
17	$\beta = 8$	A1	36	–39.57	–254.3	23	$\beta = 8$	A1	A2	–39.8	–252.7
18	$\beta = 10$	A1	36	–41.79	–262.3	24	$\beta = 10$	A1	A2	–42.17	–260.7
					$T = 0.5\ T_{max}$						
25	$\beta = 6$	C_R=C_S	36	0.902	0.530	31	$\beta = 6$	C_R=C_S	A2	0.921	0.74
26	$\beta = 8$	C_R=C_S	36	0.864	–5.94	32	$\beta = 8$	C_R=C_S	A2	0.89	–5.69
27	$\beta = 10$	C_R=C_S	36	0.771	–12.41	33	$\beta = 10$	C_R=C_S	A2	0.806	–12.13
28	$\beta = 6$	A1	36	0.904	6.329	34	$\beta = 6$	A1	A2	0.927	6.54
29	$\beta = 8$	A1	36	0.913	4.691	35	$\beta = 8$	A1	A2	0.943	4.87
30	$\beta = 10$	A1	36	0.908	4.087	36	$\beta = 10$	A1	A2	0.942	4.28

Considering the impact of basin characteristics on the selection of P, C_R and L is to enhance the simulation accuracy of partial discharge peak in the simplest way. When there are few rainfall events, especially no storms, during the snowmelt period, the improvement has no distinct effect on overall simulation (Table 3), but has a remarkable effect on the partial runoff process. Fixing the precipitation, simply adopting C_R=C_S and constant L causes a large deviation between the measured runoff and simulated runoff during some special periods and smoothes the peak discharge caused by superimposition of rainfall and snowmelt (Figure 5(c), (d)).

Figure 4 (a), (b) show that β and C_R have a certain relevance and regularity. On the one hand, C_R increases with β decreasing and that corresponding to the control range of Bayanbulak stations increased more quickly for

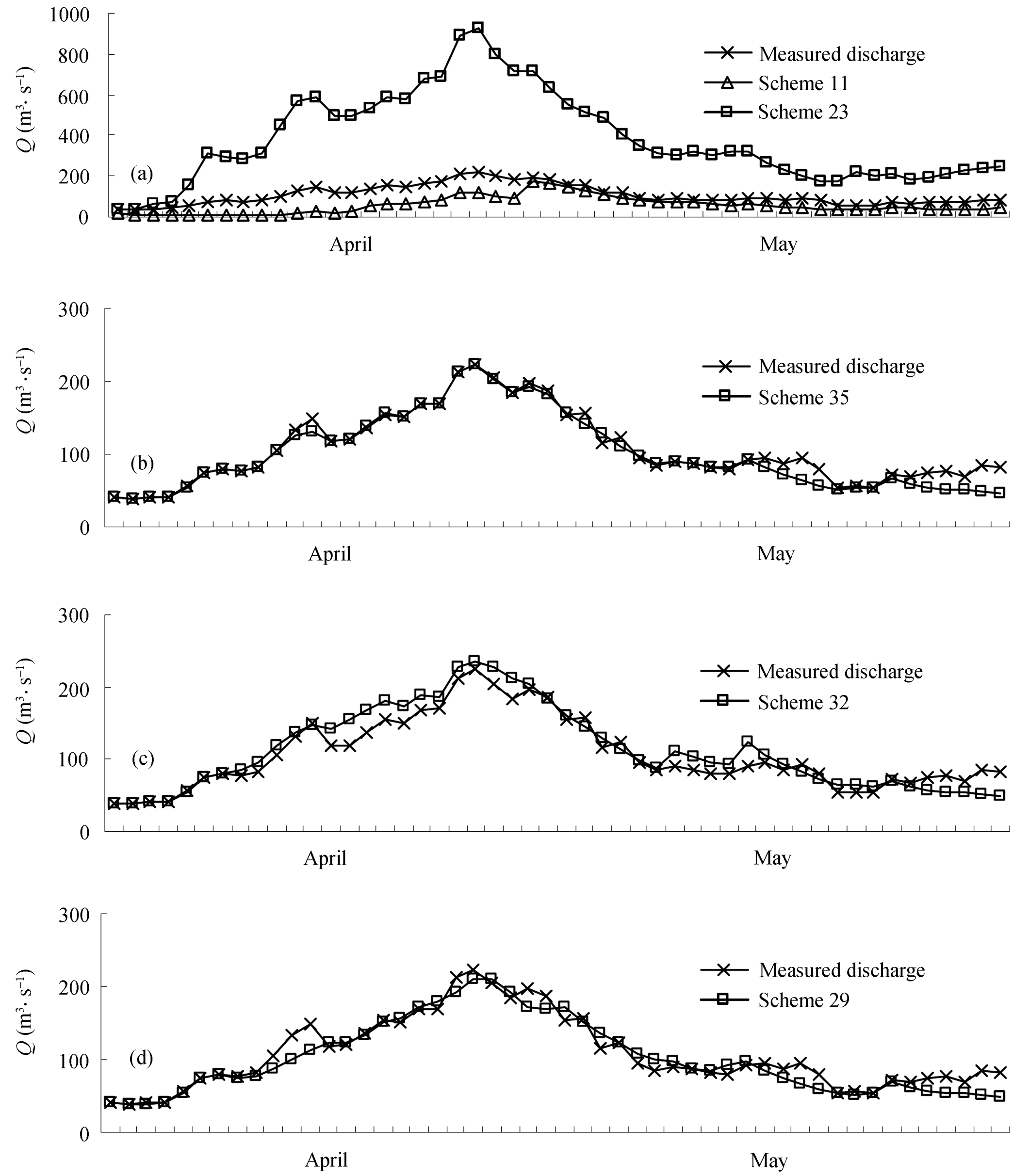

Figure 5 Snowmelt runoff simulation in the Kaidu River basin with different schemes and comparison of measured discharge with (a) scheme 11 and scheme 23 (b) scheme 35 (c) scheme 32, and (d) scheme 29.

its large area. For the upper limit of C_R to be 1, β cannot be excessively small, otherwise not enough rainfall supply can be provided. βε8 is reasonable for the Kaidu River basin. On the other hand, for a fixed β, C_R is inversely proportional to the rainfall amount. In general, $C_R \geqslant 9$ is appropriate for the Dashankou station and decreases slightly for heavy rainfalls. For Bayanbulak station, $C_R \approx 0.2$ when $P \geqslant 1$ mm/day, otherwise $C_R \geqslant 0.8$. According to the above results, we can generate an initial conclusion that the simplification of rainfall input can satisfy the simulation demands and is operable. In Figure 4(c), L shows the same tendency as the above qualitative analysis: it is 36 h for the first ten days of April and a little less for the second ten days of April; it continuously decreased during the last days of April and got to the minimum on April 29; it increased slightly with the increase of the snowmelt elevation during May except rainy days. For the numerical value, usually L is reduced to 20 h or less for rainfall events at the Dashankou station, and 30 h or less for those at the Bayanbulak station. If continuous rainfall took place, it would reduce gradually.

Among all attempts, the simulation results with the 35th and 36th schemes are the best and indicate a favorable simulation, compared with average R^2=0.84 and D_V=3.8% of the SRM applications over 80 basins in 25 different countries. The two results show that the accuracy in May is lower than that in April. Especially, after the second ten days of May, the simulation deviation gradually increases. The reason is that for the lower temperature during April, the type of precipitation is snow which had been embodied in snow cover depletion curve, namely the water from new snow has been computed; coming into May, the temperature became stable and the snowmelt supply reduced little by little. The discharge drastically increases in some short span caused by rainfall. But the remarkable spatial heterogeneity does not enable many rainfall events to be recorded by the two stations, which leads much water supply not to be computed, resulting in the simulated runoff to be lower compared to the measured runoff. This also indicates that the simulation may have very poor accuracy when the snowmelt and rainfall simultaneously supply the runoff in large basins of arid area with scarce stations, especially when the rainfall has a large proportion.

4 Conclusion and discussion

The Snowmelt Runoff Model is a relatively simple hydrological model using degree-day approach. Model has been successfully applied in many alpine basins in the world. Compared with other study areas, the basins in the arid area of northwest China have disadvantages of large area, few stations, mixed runoff supplied by snowmelt and rainfall, as well as remarkable spatial heterogeneity of rainfall, which impede the application of SRM. Based on the analysis of the impact of basin characteristics on model variables (temperature and precipitation) and parameters (runoff coefficient for rainfall and time lag), it is important for enhance ment of simulation accuracy to establish corresponding strategy of variable and parameter determination. The study of snowmelt runoff simulation in the Kaidu River basin shows that: (i) The temperature controlled the overall tendency of simulated runoff and is dominant to simulation accuracy. As the measured daily mean temperature cannot represent the average level of the same elevation in the basin, directly inputting it into the model led to poor simulations. Based on the analyses of remote sensing snow maps and simulation results, it is reasonable to approximate the mean temperature with 0.5 time daily maximum temperature. (ii) For the conflict between limited gauge station and remarkably spatial heterogeneity of rainfall, it is realistic to compute rainfall for each elevation zone. After being multiplied by a proper coefficient and adjusted with the runoff coefficient for rainfall, measured rainfall data can satisfy the model demands. (iii) Adjusting time lag according to the variation of snowmelt and rainfall position can improve the simulation precision of flood peak process. (iv) Along with temperature, the rainfall increases but cannot be completely monitored by limited gauge station, which results in precision deterioration.

Independent tests were also conducted in 2000 and 2001, and the selection of the parameters in Table 2 and T is the same as 1993. Though C_R and L are determined with the same methods, the numerical values have great difference, which is decided by the spatial heterogeneity of physical elements and the absence of data. For the large basin in arid area scarce of data, it is the data, not the model, to obstacle the level of simulation and forecast, and the model structure is up to data. Taking snowmelt runoff simulation as example, though many models delineate the hydrological process more realistically, the SRM is the preferred model for its characteristic of "using remote sensing derived snow cover". Therefore, it is most urgent to improve the monitoring level and acquirement capacity of meteorological and hydrological information based on the multiple source data, afterwards, develop the models which can sufficiently use the data. Now the SRM devotes to the development of radiation snowmelt module, the improvement of "present climate" representation and the research of the rule of model parameters variation along with the climate change, which will effectively enhance the snowmelt runoff forecast precision for the future climate. With the development of data acquirement capacity, the finer spatial discretization and the more realistic pattern of runoff generation and convergence will be adopted by SRM.

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