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Determining Critical Support Discharge of a Riverhead and River Network Analysis: Case Studies of Lhasa River and Nyangqu River

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Abstract: A riverhead is the demarcation point of continuous water channel and seasonal channel, which is characterized by a critical flow that can support a continuous water body. In this study, the critical support discharge (CSD) is defined as the critical steady flows required to form the origin of a stream. The CSD is used as the criterion to determine the beginning of the riverhead, which can be controlled by hydro-climate factors (e.g., annual precipitation, annual evaporation, or minimum stream flow in arid season). The CSD has a close correlation with the critical support/source area (CSA) that largely affects the density of the river network and the division of sub-watersheds. In general, river density may vary with regional meteorological and hydrological conditions that have to be considered in the analysis. In this paper, a new model referring to the relationship of CSA and CSD is proposed, which is based on the physical mechanism for the origin of riverheads. The feasibility of the model was verified using two watersheds (Duilongqu Basin of the Lhasa River and Beishuiqu Basin of the Nyangqu River) in Tibet Autonomous Region to calculate the CSA and extract river networks. A series of CSAs based on different CSDs in derived equation were tested by comparing the extracted river networks with the reference network obtained from a digitized map of river network at large scales. Comparison results of river networks derived from digital elevation model with real ones indicate that the CSD (equal to criterion of flow quantity (Q_c)) are 0.0028 m^3/s in Duilongqu and 0.0085 m^3/s in Beishuiqu. Results show that the Q_c can vary with hydro-climate conditions. The Q_c is high in humid region and low in arid region, and the optimal Q_c of 0.0085 m^3/s in Beishuiqu Basin (humid region) is higher than 0.0028 m^3/s in Duilongqu Basin (semi-arid region). The suggested method provides a new application approach that can be used to determine the Q_c of a riverhead in complex geographical regions, which can also reflect the effect of hydro-climate change on rivers supply in different regions.

Keywords: river network extraction; Duilongqu Basin of Lhasa River; Beishuiqu Basin of Nyangqu River; critical support discharge; hydro-climate conditions; riverhead

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1 Introduction

Hydrological analysis and network structure analysis are methods related to determining the riverhead or the demarcation point of a continuous water channel and a seasonal channel. However, the position of a riverhead is difficult to determine. In general, the catchment area above the position or the critical support/source area (CSA) is used as the judgment standard. However, selecting CSA is complex and experiential as reflected by several related studies on CSA (Montgomery and Foufoula, 1993; Jones, 2002; Li and Xu, 2012). Based on the basic conditions of the source of the river, the critical support discharge (CSD) is defined as the critical

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steady flows required to form the origin of a stream. The CSD is the range of flow variability used as the criterion to determine the beginning of the riverhead, which can be controlled by hydro-climate factors (e.g., annual precipitation, annual evaporation, or minimum stream flow in arid season).

Research on the CSD is limited and lacks a clear definition of a riverhead, but researches on similarly related concepts of eco-environmental water demand, such as low-flow and minimum in-stream flow requirements, have been often conducted (Wang *et al*., 2002; Xu *et al*., 2013; Nian *et al*., 2014). In general, low-flow may be regarded as the actual flows in a river that occurs during the dry season of the year. Low-flows are a seasonal phenomenon and an integral component of a flow regime of any river. According to Tennant (1976), 10% of average annual flow and 30% of average annual flow are needed to maintain a healthy stream environment; this finding was based on the detailed field studies conducted on 11 streams in 3 states in the U.S. between 1964 and 1974. Fraser (1978) suggested that the method used by Tennant could be extended to incorporate seasonal variation by specifying monthly minimum flows as a percentage of mean monthly flows. In the early 1970s, U.S. agencies established an approach that regulated stream pollution based their stream water quality standards on the 7-day 10-year low-flow (7Q10) condition (Singh and Stall, 1974). By the mid-1970s, minimum low-flow releases in Pennsylvania were required from impoundments higher than 1.3 km^2 (Chiang and Johnson, 1976). A low-flow of 0.01 $m^3/(s \cdot km^2)$ was initially recommended. However, this single criterion was criticized because it failed to consider watershed areas, the size of the impoundment, or the natural low-flow yield of the regulated stream. The water quality of any stream was considered acceptable unless the stream flow was below the 7Q10. Any diversion made beyond the 7Q10 could degrade the water quality of the stream beyond the accepted standard (Chiang and Johnson, 1976). These hydrological methods considered the discharge in the view of eco-environmental water demand, which are typically desktop techniques that primarily rely on published hydrological data in the form of historical monthly or daily flow discharge data, to make environmental flow recommendations (Tharme, 2003).

Considerable studies on low-flow have been conducted, but these studies disregarded the CSD. The CSD of a riverhead is regarded as CSA (Martz and Garbrecht, 1992), which defines the minimum drainage area required to form the origin of a stream with a steady flow (Montgomery and Dietrich, 1992; Yang and Ren, 2009). On a digital elevation model (DEM), the grids within the CSA are generally considered as the birthplace of the river (Montgomery and Foufoula, 1993; Jones, 2002). Similarly, the CSD is also an altered flow regime (by means of climate change), but is not lower than the lower bound of low-flow. The ecological result of different flow regimes might need to be considered. However, setting flow targets based on ecological information is hard to achieve (Gain *et al*., 2013). In the absence of extensive ecological information, Richter *et al*. (1997) suggested several measures of dispersion (e.g., the range, ±1 or 2 standard deviation (SD), the twentieth and eightieth percentiles, *etc*.) to set initial threshold flows. Therefore, values at ± 1 SD from the CSD were selected as thresholds for the CSD. Thus, the CSD should stay within the limits: CSD – SD ≤ CSD ≤ CSD + SD.

China is one of the countries that own the largest rivers in the world, and there are many long-standing major rivers, such as the Huanghe (Yellow) River and the Changjiang (Yangtze) River in China. More than 1500 rivers have more than 1000 km^2 of basin area. These rivers are important parts of the Chinese geographical environment and are rich in natural resources. Furthermore, the riverheads of most rivers in China originated from the Tibet Autonomous Region. A riverhead is an important symbol of the environment of the river formation, which reflects the influence of different regional hydrology and climate change on river supplies that are essential to determine the riverhead of a river. Therefore, research on a riverhead in Tibet is significant.

Tibet is a driver and amplifier of global climatic change (Pan and Li, 1995; Sun *et al*., 2013a; 2013b) and the birthplace of several Asian rivers. Research on critical support flow can be used as the indicators of river change in Tibet and can be used to reflect the impact of climate change, which is significant to the research on global climate change. However, determining the thresholds of the CSD of a riverhead is complex and few studies have been conducted in Tibet.

In this study, an approach was presented to calculate the threshold of the CSD in the riverhead with hydro-climate data. Moreover, it was applied in two basins located on the east-central rivers of Tibet. The CSD model considers the natural climatic and hydrologic variability, and it is versatile enough to be applied at large scales. The methodology is based on the main principles of the water balance, and it satisfies the hydrologic requirements of Tibet.

2 Materials and Methods

2. 1 Study area

The Duilongqu Basin of the western Lhasa River and the Beishuiqu Basin of the western Nyangqu River (Fig. 1) are selected as the study area and are used to analyze CSA. These two sub-basins are located in the lower part of the two rivers and represent the semi-arid climate region (the Lhasa River) and humid climate region (the Nyangqu River).

The Lhasa River and Nyangqu River are tributaries of the Yarlung Zangbo River in China. The Lhasa River is located in the middle of the Yarlung Zangbo River and is its largest tributary, originating from the south of the Tanggula Range. Its elevation difference is 1620 m from the head waters at an elevation of 5200 m to the outlet of the river to the Yarlung Zangbo River at an altitude of 3580 m. The Nyangqu River originates from the western side of the Mila Mountain in the Qinghai-Tibet Plateau, running from the west to east and flowing into the Yarlung Zangbo River near Nyingchi County in Tibet.

As a result of topography, more precipitation is observed in the southern mountains and less in the northern plateau; more in upper reaches and less in downstream valley. Precipitation decreases from the southeast (700–800 mm) to the northwest (300–400 mm) in the study area (Zheng *et al*., 1979; Shen, 1995). The evaporation on water surface observed by E601 evaporator varies from 1000 mm to 1300 mm in the Qinghai-Tibet Plateau (Du *et al*., 2008; 2009), but the land evaporation in watershed scale is lower than the observation value on water surface evaporation.

This study is focused on the CSD related to the discharge in the lower Yarlung Zangbo River Basin, which belongs to the Qinghai-Tibet Plateau where the hydrological impact of climate change is expected to be particularly strong (Immerzeel *et al*., 2010; Gain *et al*., 2011). The major meteorological stations of the lower Yarlung Zangbo River are in the eastern and central Tibet in which long-term observed records (precipitation and temperature) are available through the China Meteorological Administration (http://www.cma.gov.cn/en/). The data are of high quality and are used in most hydrological studies for flood forecasting and other planning purposes (Gain *et al*., 2011).

2.2 Methodology

The river or stream is the channel through which water flows. Stream flow decreases along the channel as it moves from the downstream position to the upstream position. Water flow is traced back upwards along the stream. If the flow decreases to a critical value, in which the bottom of the river channel can no longer be covered by a continuous water body, the stream can not maintain its steady flow. Thus, the riverhead can not be supported by runoff water, and this point will be regarded as the origin of a river.

The CSD, which is defined as the critical steady flows required to form the origin of a stream, usually varies within flow regime 0.001–0.010 m^3/s in Tibet and can be taken as the criterion of flow quantity (Q_c) to recognize the beginning of riverhead (O'Callaghan and Mark, 1984; Quinn *et al*., 1991; Montgomery and Dietrich, 1992). Stream flows in Tibet considerably change with seasons. Under these circumstances, Q_c is

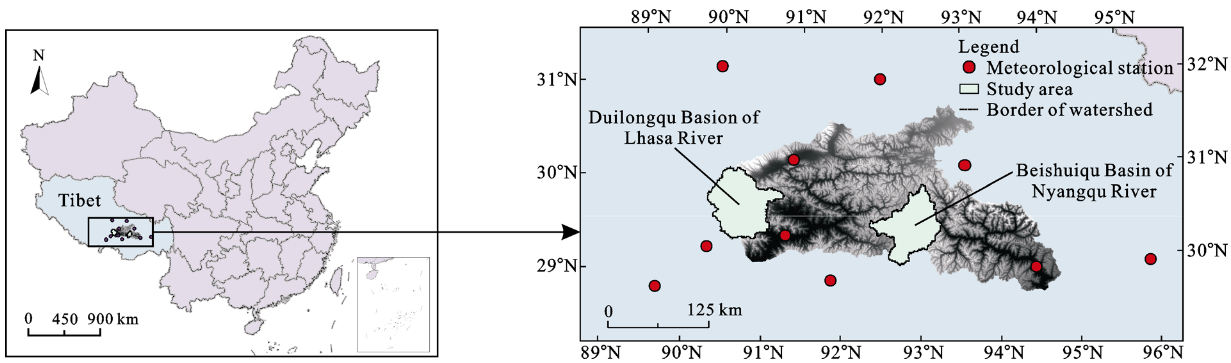

Fig. 1 Study area and meteorological stations surrounding Lhasa River and Nyangqu River

usually compared with the minimum monthly average discharge (Q_{min}, usually used as low-flow) which is a proper index to define the rough range of the CSD. Only when $Q_c \geq Q_{min}$, the channel is considered a river. Otherwise, the channel should be regarded as a dry ditch or valley trough.

The Q_{min} is the minimum monthly average discharge of a river, which usually occurs during the last month of the dry season (usually in March in Tibet) (Gain *et al.*, 2013). The Q_{min} is related to the annual average discharge (Q_a) in a proportional relationship. For rivers in the southwest China, $Q_{min} = C_0 \times Q_a$, where C_0 is a constant within 0.15 –0.20 for most rivers (Hu *et al.*, 2006; Zhong *et al.*, 2006; Gain *et al.*, 2011).

The Q_a is a characteristic parameter of a river determined by regional meteorological and hydrological factors. Hydro-meteorological conditions determine the annual runoff volume (W_a) of a basin, which can be calculated from annual precipitation (P) and annual evaporation (E) by the water balance equation of the watershed. The following relationships exist:

$$Q_a = W_a / T_a = F \times (P - E) / T_a \quad (1)$$

Thus, $F = Q_a \times T_a / (P - E)$ or $F = Q_{min} \times T_a / C_0 \times (P - E)$ (2)

where F and T_a represent the areas of the catchment and time length in a year, respectively.

The CSA of the riverhead is defined as the critical catchment area that contributes to the critical discharge to support the riverhead with a steady flow. Thus, when the Q_{min} is replaced by the CSD (equal to Q_c), the CSA of the riverhead will be:

$$F_c = Q_c \times T_a / C_0 \times (P - E) \quad (3)$$

In Equation (3), P and E can be calculated from the observation data of the meteorological stations and then interpolated into the study area. The T_a is a constant (365 × 86400 s) and Q_c is the CSD, which can be determined by best fitting the derived river network to the real river network. Equation (3) facilitates the relationship of F_c (CSA) to hydro-climate parameters and can be regarded as the rational method.

For the situation without evaporation observation data in study area, E must be calculated by a proper approach. Takahashi (1979) suggested and tested an applied method to calculate land evaporation from monthly temperature and precipitation of regional data as follows:

$$E_m = 3100P_m / [3100 + 1.8P_m^2 \times \exp(-34.4T_m / (235 + T_m))] \quad (4)$$

where E_m, P_m, and T_m are monthly mean evaporation, monthly mean precipitation, and monthly mean temperature, respectively.

Fu *et al.* (2012) improved the method used by Takahashi by considering the impacts of the frozen soil and ice-snow thawing on high altitude area. They verified the improved formula by observation data of the Lhasa River watershed, and proved that the modified results are precise and suitable to be applied on the Qinghai-Tibet Plateau.

In the conventional approaches of geographic information system (GIS) hydrological analysis, the CSA determines the calculated network results and displayed appearance of the starting point of the waterway (Li, 2007). The similarities of the derived river network were compared with the real ones by including the river density index (ρ), which is the ratio of total length of the rivers (L_r) to total area of the watershed (F_r). The longer the river, the higher the ρ value is. The density indices calculated from the derived rivers (ρ_c) and actual rivers (ρ_r) represent the similarity of the drainage density for the derived rivers. The fitness of the rivers shown on the topographic maps is an indication of the degree of similarity between the two networks.

The optimized Q_c based on Equation (3) is confirmed when the best fitness between derived river network and the actual network appears. The minimum threshold (CSD – SD) and maximum threshold (CSD + SD) for the CSD are used as range of the CSD.

2.3 Data source and data processing

Elevation data from the Shuttle Topography Mission with a ground resolution of 90 m × 90 m, released by United States Geological Survey (USGS) (https://wist.echo.nasa.gov/), was used for modeling and enhanced geomorphological mapping. The drainage network of the basin was extracted. A topographic map on the scale of 1 : 250000 was used as a geographic base map to extract the river networks in the study area.

The T_m and P_m from 10 meteorological stations surrounding the study area during 1982–2002 (Fig. 1 and Table 1) were also collected and used in this study. Given no meteorological station within the two basins, the monthly temperature and precipitation data of 10

Table 1 Climate characteristics of surrounding meteorological stations of study area

Station	Lhasa	Damxung	Lhari	Nyingchi	Nyêmo	Zêtang	Bowo	Nagqu	Baingoin	Gyangzê
Latitude (N)	29°40′01″	30°28′59″	30°40′01″	29°40′01″	29°25′59″	29°15′00″	29°52′01″	31°28′59″	31°22′59″	28°55′01″
Longitude (E)	91°07′59″	91°06′00″	93°16′59″	94°19′59″	90°10′01″	91°46′01″	95°46′01″	92°04′01″	90°01′02″	89°36′00″
Elevation (m)	3649	4200	4488	2991	3809	3552	2736	4507	4700	4040
Temperature (℃)	8.2	1.6	–0.5	8.9	7.2	8.6	8.8	–1.4	–1.1	4.9
Annual precipitation (mm)	446	482	732	709	349	385	742	336	253	288

stations around were interpolated into each grid of the study area by cokriging method or arithmetical average. All calculations of interpolation and spatial statistics are conducted in a GIS environment using ArcGIS 10.0 by Environmental Systems Research Institute, Inc. (ESRI).

3 Results

The meteorological data of meteorological stations surrounding the study area were interpolated into the Duilongqu Basin and Beishuiqu Basin. The annual precipitation is computed for the Duilongqu Basin (457 mm) and Beishuiqu Basin (720 mm). The average annual evaporation of watershed is computed by improved Takahashi formula for the Duilongqu Basin (388 mm) and Beishuiqu Basin (408 mm). Parameter (C_0 = 0.175) was obtained based on the hydrological records of the Lhasa River and the Nyangqu River. The CSD method is used to calculate the critical area (F_c). The ArcGIS was applied to extract the river network. The optimal values of F_c, reflect the environment of the Duilongqu Basin and Beishuiqu Basin and were determined by calculating the ratio (ρ_c/ρ_r) of drainage density and actual drainage density.

A set of reference values for Q_c are selected based on the CSD method (Equation 3) to calculate the F_c (Table 2). The river networks were extracted through Soil and Water Assessment Tool (ArcSWAT) from DEM using the derived F_c (Fig. 2 and Fig. 3). The results show that the lower the value of F_c, the denser the river network and the more complicated the network structure is. Therefore, Q_c is the key parameter for controlling the F_c that influences the computed results of the river network. The higher the Q_c value, the lower the ρ_c should be. When the ρ_c/ρ_r is equal to 1.004, the Q_c is 0.0028 m^3/s for the Duilongqu Basin, and when the ρ_c/ρ_r is equal to 0.991, the Q_c is 0.0085 m^3/s for the Beishuiqu Basin (Table 2). Thus, the river network extracted from the DEM of the Lhasa River and Nyangqu River is mostly similar to the actual river network. In this condition, the CSD for the Duilongqu Basin and Beishuiqu Basin are 0.0028 m^3/s ± SD (SD = 0.001 m^3/s) and 0.0085 m^3/s ± SD (SD = 0.001 m^3/s), respectively. The minimum threshold values for the Duilongqu Basin (0.0018 m^3/s) and the Beishuiqu Basin (0.0075 m^3/s) are higher than the minimum monthly average discharge (0.001 m^3/s). Therefore, the results agree with $Q_c \geq Q_{min}$.

Table 2 Results of main parameters for critical support discharge (CSD) method for study area

Duilongqu Basin (P = 457, E = 388, C_0 = 0.175)						Beishuiqu Basin (P = 720, E = 408, C_0 = 0.175)					
Q_c (m^3/s)	Q_c/C_0	F_c (km^2)	ρ_c	ρ_r	ρ_c/ρ_r	Q_c (m^3/s)	Q_c/C_0	F_c (km^2)	ρ_c	ρ_r	ρ_c/ρ_r
0.0100	0.057	26.12	0.106	0.377	0.281	0.020	0.114	11.55	0.154	0.365	0.421
0.0080	0.046	20.89	0.132	0.377	0.351	0.015	0.086	8.66	0.205	0.365	0.562
0.0050	0.029	13.06	0.212	0.377	0.562	0.010	0.057	5.78	0.307	0.365	0.842
0.0030	0.017	7.84	0.353	0.377	0.937	0.009	0.051	5.20	0.342	0.365	0.936
0.0028	0.016	7.31	0.379	0.377	1.004	0.009	0.049	4.91	0.362	0.365	0.991
0.0026	0.015	6.79	0.408	0.377	1.081	0.008	0.046	4.62	0.384	0.365	1.053
0.0024	0.014	6.27	0.442	0.377	1.171	0.005	0.029	2.89	0.615	0.365	1.685
0.0022	0.013	5.75	0.482	0.377	1.278	0.003	0.017	1.73	1.025	0.365	2.808
0.0020	0.011	5.22	0.530	0.377	1.406	0.002	0.011	1.16	1.537	0.365	4.212
0.0010	0.006	2.61	1.060	0.377	2.811	0.001	0.006	0.58	3.075	0.365	8.424

Notes: P, annual precipitation; E, annual evaporation; Q_c, critical flow that supports river; F_c, critical support area of the watershed; ρ_c, derived rivers density index; and ρ_r, actual rivers density index

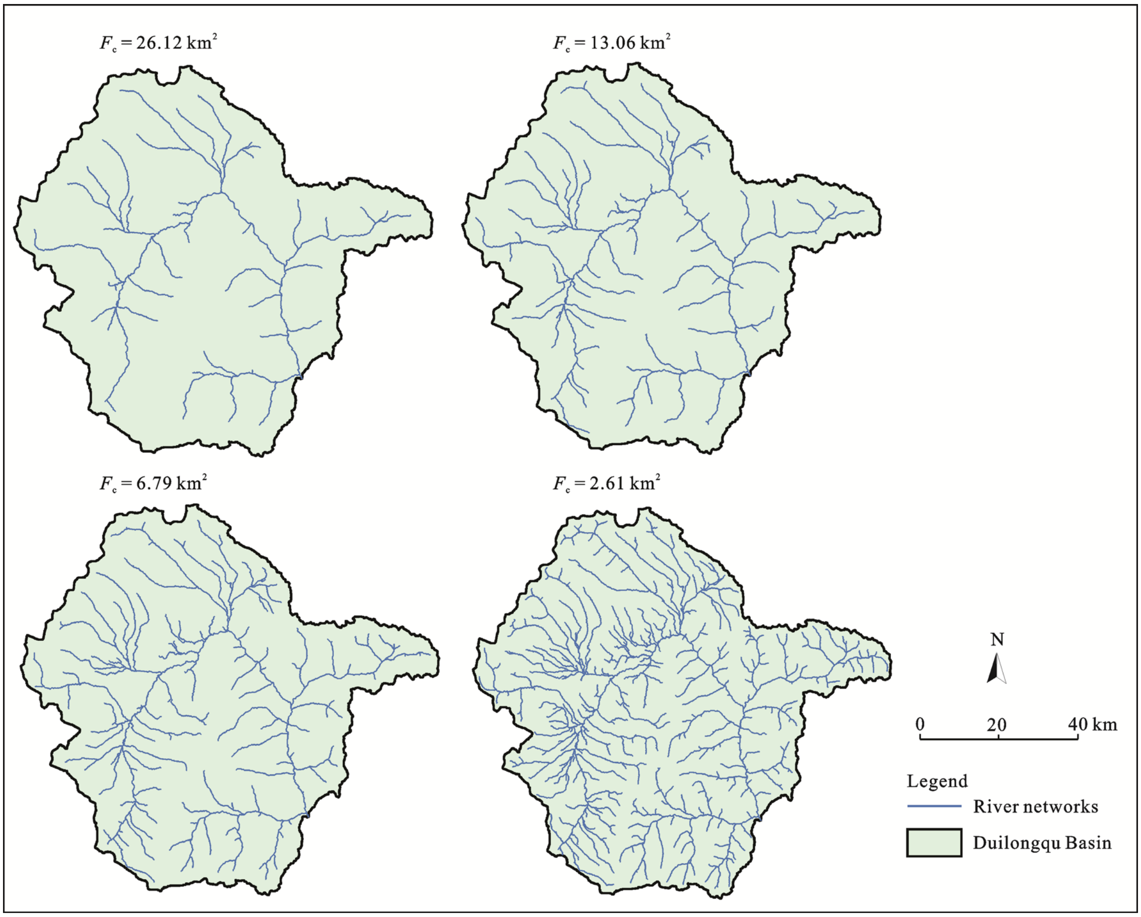

Fig. 2 River networks of Duilongqu Basin extracted via different threshold values of support area

The rationality of Q_c are verified using the extraction river network of the Lhasa River or the Nyangqu River. The actual topographic map of each river is drafted by overlaying and contrasting (Fig. 4). The results show that the distribution and structure of the derived river network sufficiently coincided with the actual river network.

4 Discussion

The accuracy evaluation of Q_c, F_c, ρ_c/ρ_r for the CSD method was analyzed in Results. Further discussion of these parameters is essential to understand its validity on hydrologic process research. In the proposed model, the key parameter is the Q_c, which affects the CSA of basin. According to the results of this study, the optimal values of Q_c in the Lhasa River and Nyangqu River were 0.0028 m^3/s and 0.0085 m^3/s, respectively. The Q_c varies with the climate condition, and it is high in humid region while low in semi-arid region. The Q_c of the Lhasa River is 67% lower than that of the Nyangqu River, which indicates that the initiation of the Lhasa River is less low-flow and more severe climate condition than the initiation of the Nyangqu River is. The annual average runoff of the Lhasa River is 278.1 m^3/s, while that of the Nyangqu River is 559 m^3/s. On the annual average scale, river runoff in Tibet reflects the synthetical effects of regional climate and natural hydrologic conditions (Lin *et al*., 2007). The characteristics of runoff are a response to climate condition (temperature and precipitation), while the Q_c is positively correlated with the runoff. Therefore, different Q_c represents the different local meteorological and hydrological conditions.

At CSD model, the riverhead could be supported by a continuous stream flow, and the node with stream flow Q_c could be regarded as the beginning of the river. The Lhasa River and Nyangqu River represented the semi-arid and humid regions, respectively. These climatic differences result in different river densities. Notable river density discrepancies were revealed in F_c (Fig. 4). The values of F_c calculated from the Lhasa River and

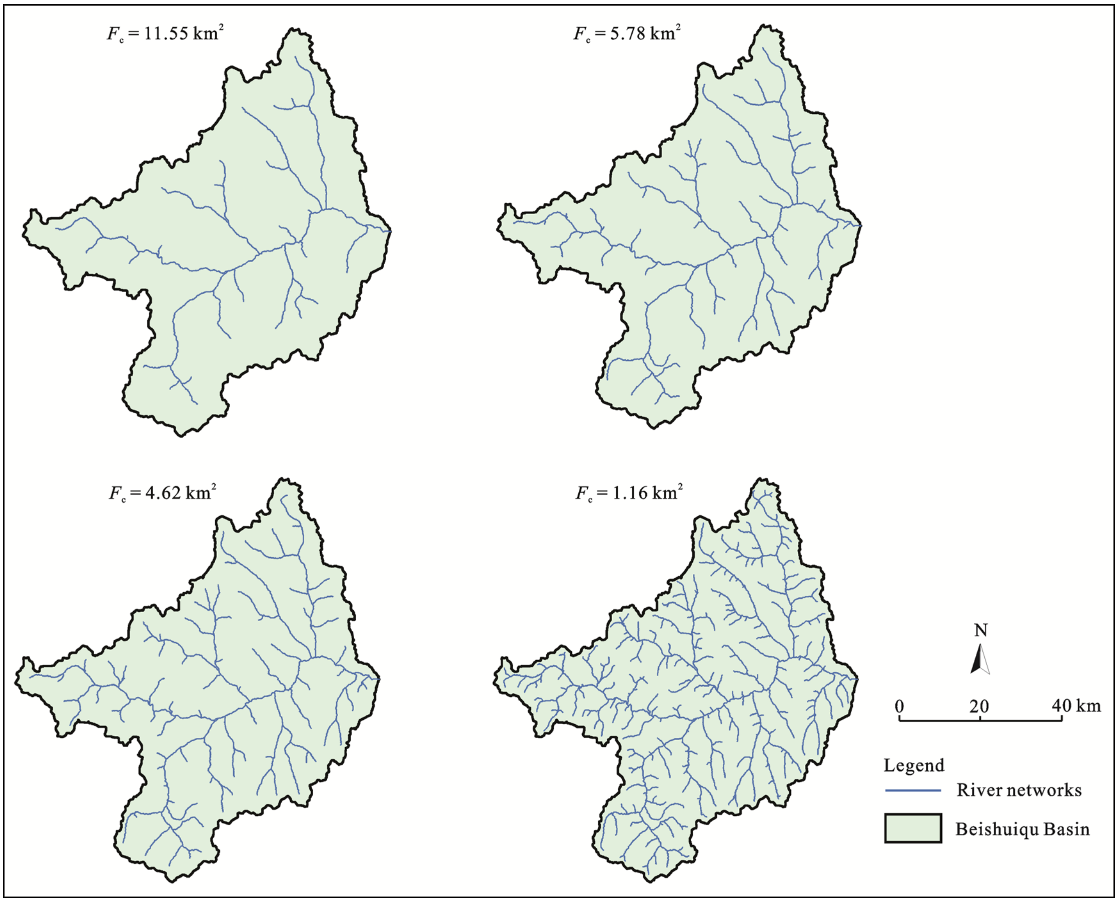

Fig. 3 River networks of Beishuiqu Basin extracted via different threshold values of support area

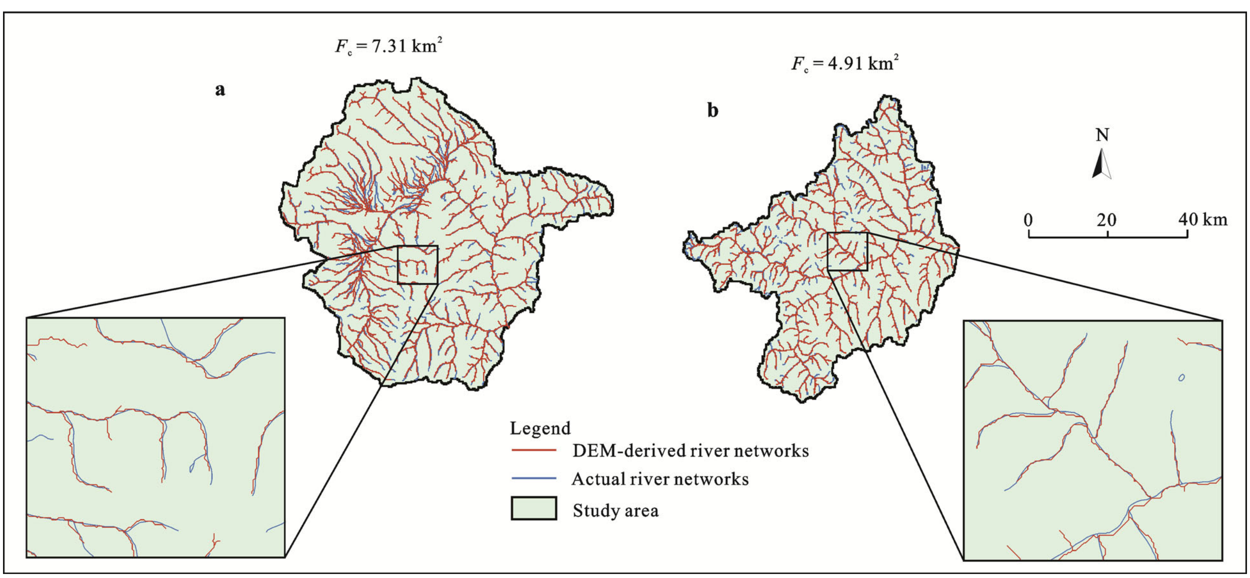

Fig. 4 Comparison of river networks derived via critical support discharge (CSD) method with digital stream map. a, Lhasa River (F_c = 7.31 km^2); b, Nyangqu River (F_c = 4.91 km^2)

Nyangqu River were obtained through the CSD model. By using the derived F_c, the river networks could be automatically extracted from DEM via ArcGIS. The CSA for the Duilongqu Basin of the Lhasa River (F_c = 7.31 km^2) is higher than that of the Beishuiqu Basin of the Nyangqu River (F_c = 4.91 km^2), which reflects the climatic differences (semi-arid and humid) between the two study basins (Hu *et al*., 2006; Zhong *et al*., 2006; Gain *et al*., 2011). The results of Fig. 2 and Fig. 3 show that different F display different river networks. The F value is inversely proportional to ρ. The ρ_c/ρ_r is the ratio of derived rivers density index and actual rivers density index, which reflects the similarity of actual river networks and derived river networks acquired through the CSD model. In Table 2, a series of ρ_c/ρ_r were achieved by different F calculated in the CSD model. When the value of ρ_c/ρ_r is approximately 1.0, Q_c of the Duilongqu Basin is 0.0028 m^3/s, while that of the Beishuiqu Basin is 0.0085 m^3/s. The results of Fig. 4 show that the drainage densities of the Duilongqu and Beishuiqu basins reflect the correlation of threshold of F, which is similar to the conclusion of Liu *et al*. (2014).

Table 3 shows that the relative error of drainage density of the Duilongqu Basin is 0.53%, while that of the Beishuiqu Basin is 0.82%. The results of the study area satisfy the hydrologic requirements of Tibet. The rationality of the CSD method can also be tested by comparing derived river networks with actual river networks and determining the thresholds (Fig. 4 and Table 3).

The comparison results indicated that when the optimal value of Q_c is confirmed, the distribution and structure of these two river networks were extremely similar. The statistical indices of the length, numbers, and density of the river were likewise extremely close in values (Table 3).

In this study, the CSD was determined by using the CSD model, which established the relationship between F_c and Q_c, extracted the networks, and determined the optimal value. Meteorological and hydrological factors have important implications for stream processes and patterns (Poff *et al*., 1996), which affect the abiotic factors (river gradient, depth of water, and river flow) of the Yarlung Zangbo River that have a strong effect on its hydrobiology (Boruah and Biswas, 2002). The study of the CSD provides a new approach to assess the effect of climate change and ecohydrology change.

5 Conclusions

Previous studies have been limited to low-flow and its ecological effect by different methods. This study presented the definition of the CSD and proposed the CSD model. The suggested CSD method represented the physical mechanism of the runoff generation under regional climatic conditions (precipitation and evaporation). Based on the CSD method, hydrological data such as precipitation, evaporation, and minimum monthly flow of study area were considered to determine the CSA of a basin. The DEM with 90 m grid resolution was used to extract the networks of the Lhasa River and Nyangqu River. The results indicated that the distribution and structure of the extracted river network sufficiently coincided with the actual river network. The results of this study from different climate regions demonstrated that the proposed method to determine the CSD is highly reliability.

Only the CSD (Q_c) that infers the CSA (F_c) based on regional meteorological and hydrological factors has been focused on in Tibet. In reality, the relationship between them may be complex because of several parameters (e.g., vegetation cover, soil transmissibility, and bedrock erodibility or lithology). However, the CSD method based on water balance in large scale and long-term time series is reliable. The proposed approach to determine the CSD in Tibet may also be useful in other river basins. In determining the CSD in other related factors (e.g., geology, ecology), future studies should conduct an extensive application in the CSD method that considers different meteorological and hydrological regions.

Table 3 Comparison between extracted river network and actual river network for Duilongqu Basin and Beishuiqu Basin

Characteristic parameter		Catchment area (km^2)	River length (km)	Number of rivers	Drainage density (km/km^2)
Duilongqu Basin	Actual network	4574.6	1726.8	445	0.377
	Derived network	4531.5	1807.8	460	0.379
	Relative error (%)	0.94	4.69	3.37	0.53
Beishuiqu Basin	Actual network	4023.0	1468.7	515	0.365
	Derived network	3986.2	1456.7	525	0.362
	Relative error (%)	0.91	0.81	1.94	0.82

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